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The Ecology of Albemarle Sound, North Carolina: An Estuarine Profile

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Upper photograph: LANDSAT print of Albemarle Sound, NC, courtesy of the National Aeronautics and Space Administration.

Lower left photograph: Freighter Albemarle taken around the turn of the century, courtesy of the North Carolina Department of Archives and History.

Lower right photograph: Bald cypress stand along the swamp forest shoreline of Albemarle Sound.

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THE ECOLOGY OF ALBEMARLE SOUND, NORTH CAROLINA: AN ESTUARINE PROFILE

by

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PREFACE

This estuarine profile is part of an emerging series of publications concerning current issues facing the Nation's estuaries. Its purpose is to synthesize existing information describing the structure and function of Albemarle Sound, North Carolina. Albemarle Sound and its associated tributary estuaries represent a vast complex of freshwater to brackish water creeks, rivers, and open-water sounds. This complex, the northernmost component of the extensive North Carolina coastal system, constitutes a significant portion of the system.

The profile is a state-of-the-art synthesis, bringing together all available information on Albemarle Sound, especially that critical to managing the estuary. In many instances, critical gaps exist in information needed to affect management. We have identified the gaps, suggested comparisons with similar estuarine systems in other sections of the country or world, and described ways that the missing information may be accommodated.

Because the estuary is an intact, integrated unit, we are approaching the profile from a systems viewpoint. No single function or component operates in isolation from another. Likewise, the integrated estuary does not function in isolation from the streams entering it, the land around it, the estuaries and sounds connected to it, or the ocean adjacent to it. Thus, this profile attempts to describe the geological, biological, chemical, and physical characteristics of Albemarle Sound and then to spatially and temporally relate the components to illustrate the integrated estuarine system. Finally, in Chapter 6, we have suggested a multi-faceted management strategy tempered by socio-economic realities and institutional constraints.

Albemarle Sound has received considerable attention in recent years. During the past decade, the fisheries catch has declined about 70%; and nuisance algal blooms on a major tributary (the Chowan River) have lowered property values, discouraged tourism, and caused fish kills. Changing land uses, increasing industrial and residential development, and freshwater diversions have been implicated. In response to these conflicts, the North Carolina General Assembly has ordered a joint agency/citizen's study of the sound and preparation of an action plan designed to identify study needs and management strategies. This profile encompasses these needs and should be useful in assisting these important efforts.

The findings in this report are not to be construed as an official U.S. Fish and Wildlife Service position unless so designated by other authorized documents. Statements of conclusions, as well as suggested courses of study or action, are exclusively those of the authors.

Any questions or comments about, and(or) requests for, this publication should be directed to:

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ACKNOWLEDGMENTS

We are indebted to many colleagues and former students who have provided much of the information reported here. Much of the research described in this profile was made possible by the extensive programs of the University of North Carolina's Sea Grant College Program and Water Resources Research Institute. Extensive contributions were made to the overall knowledge of Albemarle Sound by the North Carolina Division of Environmental Management and Division of Marine Fisheries in the North Carolina Department of Natural Resources and Community Development.

We appreciate all those who reviewed and improved the manuscript, especially Edward Pendleton and other members of the National Coastal Ecosystems Team, Mike Gantt and the Fish and Wildlife Service field office at Raleigh, and Preston Pate, whose special knowledge of the sound was particularly helpful.

Photographs were selected and prepared by Neil Caudle, who was also helpful with suggestions for improving the manuscript. Carolyn Cessna labored tirelessly in making a readable script from our dictaphone tapes. Mary Fotch, Connie Ross, MariAnne Gill, Cindy Etter, and Lisa Randall typed the final manuscript and manipulated the word processor to incorporate last-minute corrections.

The final copy was edited at the National Coastal Ecosystems Team by Randy Smith, Gaye Farris, Kathryn Lyster, and Charlotte Willett. Word-processor operators Betty Brody, Elizabeth Krebs, and Daisy Singleton produced the camera-ready version. Sue Lauritzen completed final layout of the camera-ready manuscript.

CHAPTER 1

INTRODUCTION - THE SETTING

1.1 ALBEMARLE SOUND AS A NATURAL UNIT

Albemarle Sound and its associated tributary estuaries in northeastern North Carolina represent an extensive complex of freshwater to brackish water creeks, rivers, and open water sounds (Figure 1). The estuarine shoreline of the entire system exceeds 800 km (500 mi) and spans nine counties: Bertie, Camden, Chowan, Currituck, Dare, Pasquotank, Perquimans, Tyrell, and Washington. Albemarle Sound is oriented approximately east to west and extends from the mouth of the Roanoke River, about 8 km (5 mi) northeast of the town of Plymouth, eastward about 90 km (56 mi) to Kitty Hawk Bay and Colington Island on the Outer Banks. The main estuary gradually widens from less than 5 km (3 mi) at the State Highway 32 bridge in the western portion, to over 20 km (12 mi) wide in the area of the Alligator, North,

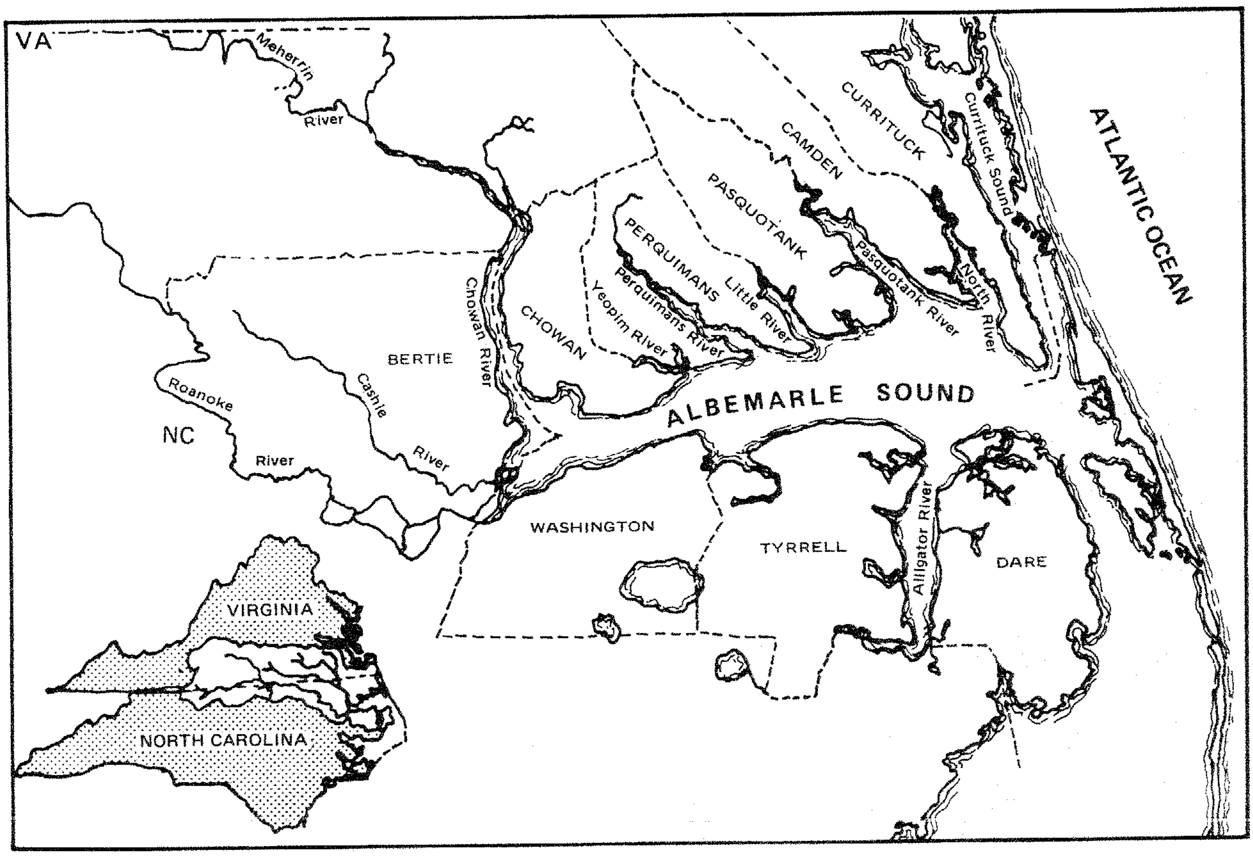


Figure 1. Map of the Upper North Carolina Coastal Zone and Albemarle Sound.

and Pasquotank Rivers in the east. The Albemarle Sound estuarine system includes seven major embayed lateral estuaries and numerous small embayed lateral streams. On the north, the major lateral estuaries are, from west to east, the Chowan, Perquimans, Little, Pasquotank, and North Rivers; the Scuppernong and Alligator Rivers are on the south. Covering 125,000 ha (500 mi^2), the estuary is a significant portion of the North Carolina coastal system.

Albemarle Sound, which is generally perpendicular to the ocean shoreline, is the drowned portion of the Roanoke River and its extensive floodplain. Numerous lateral tributaries drain the low, flat, swampy coastal plain and discharge relatively small amounts of acidic blackwater into the sound. Consequently, the sediment load in Albemarle Sound is small and suspended solid materials are dominated by organic matter derived from the broad floodplain swamp forests and inland pocosins.

On the eastern end of Albemarle Sound are several open-water estuaries. These are parallel to the ocean and Outer Banks and include the freshwater Currituck Sound on the north and the brackish Croatan and Roanoke Sounds on the south. Because of the low, flat topography of the adjacent lands, the geographic orientation and large size of the sound, and the long fetch over shallow waters, wind energy dominates Albemarle Sound. The absence of a direct communication with the Atlantic Ocean results in strong freshwater and minimal oceanic influences.

1.2 GEOLOGICAL ORIGIN AND EVOLUTION

The entire Albemarle Sound region is underlain by an eastward thickening wedge of sediments and sedimentary rocks deposited on the same type of crystalline rocks that occur in the Piedmont of North Carolina (Figure 2). Thick beds of marine sediments were deposited at various times when the ocean covered portions of the Coastal Plain. Thinner beds were deposited as part of the coastal system as the shoreline migrated back and forth across the Coastal Plain-Continental Shelf (Brown et al. 1972).

The resulting wedge of sedimentary rock has been subdivided into a series of formations. Each formation has a defined

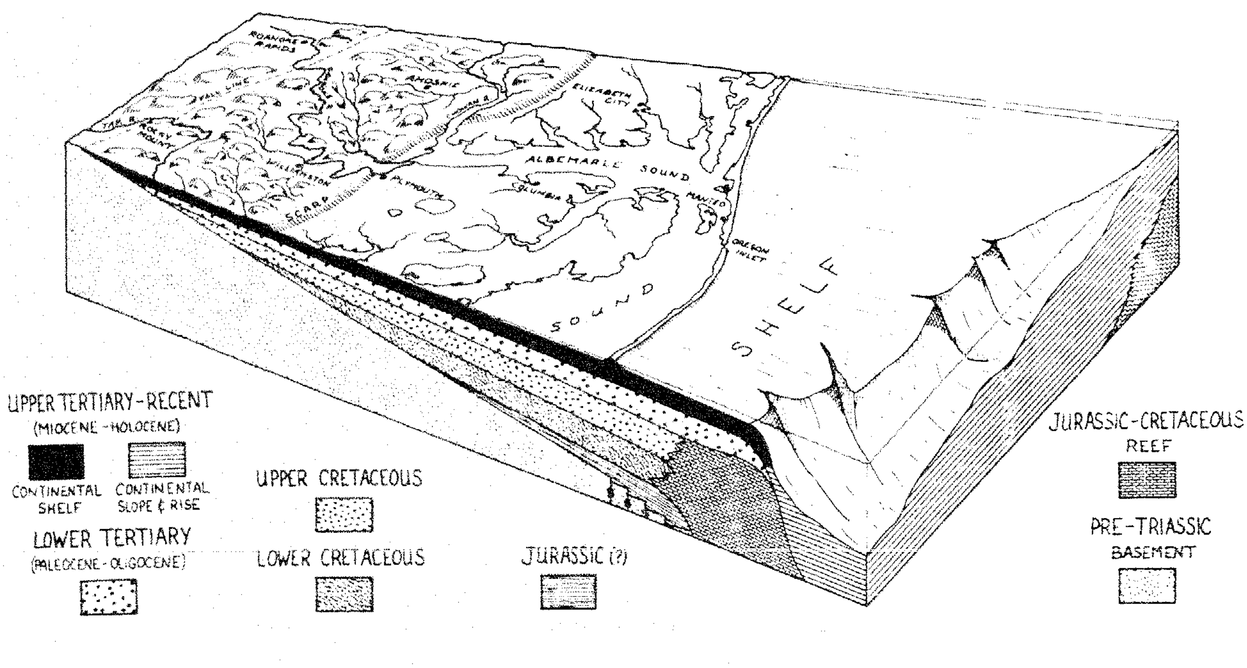


Figure 2. Cross-section of the stratigraphy of northeastern North Carolina.

position and age within the sequence and a distinctive textural, mineralogical, and fossil composition. The names and ages of the formations are presented in the cutaway cross section of the North Carolina Coastal Plain-Continental Shelf (Figure 2). Most of these units have little direct influence on the sound and will not be discussed. The uppermost veneer of unconsolidated sediments does have a direct influence, however, since these sediments dictate the general characteristics of the estuarine system, including the regional geography and character of the estuarine margins and bottoms as well as the topography, soil types, water drainage, and land use of the adjacent land areas.

Sediments deposited within the rapidly changing sequence of coastal environments during the recent geologic periods are extremely varied and complex and include gravels, sands, clays, and peats in all possible combinations (Hartness 1977). Most of these units are not fossiliferous, or, if they had contained fossils, the fossils often have been partly or completely leached out by the acid groundwaters moving through the surface aquifers. The Pleistocene sediments range in thickness from a few meters up to 15 m (49 ft) throughout the inner and middle estuarine areas and increase to 25 m (82 ft) in the outer areas of the Albemarle Sound Estuary (Table 1).

During the Pleistocene Epoch, numerous massive ice sheets formed in the polar regions and moved southward across the northern portions of the European, Asian, and North American continents. In North America, the ice sheets came as far south as the Missouri and Ohio Rivers and extended across New York, New Jersey, and onto the New England Continental Shelf. The development of mile-thick ice sheets that covered such vast areas required tremendous volumes of water. Consequently, the periods of ice advance were accompanied by worldwide lowering of sea level by as much as 100 m (330 ft) (Fairbridge 1960). Conversely, the retreat and melting of these ice sheets brought about worldwide sea level rise, which was often in excess of the present sea level (Figure 3).

To consider the dynamics of the present Albemarle Sound estuarine system, the Pleistocene history for the past 35,000 years must be reviewed. At that time, the world was experiencing an interglacial period in which the North Carolina coastal and estuarine system would have occupied approximately its present geographic position (Fairbridge 1960). Then, world climates began to cool and the last major glacial ice advance was initiated, culminating in a maximum development at approximately 15,000 to 17,000 years B.P. (before present). At that time, the glacial

Table 1. Stratigraphic section at Aurora, NC. Similar formations of these thicknesses underlie the Albemarle Sound.

Age	Formation	Thickness
Pleistocene	Post-Croatan Croatan	3 - 15 m 1 - 25 m
Pliocene	Upper Yorktown Lower Yorktown	2 - 20 m 2 - 4 m
Miocene	Pungo River	20 - 25 m
Eocene	Castle Hayne	

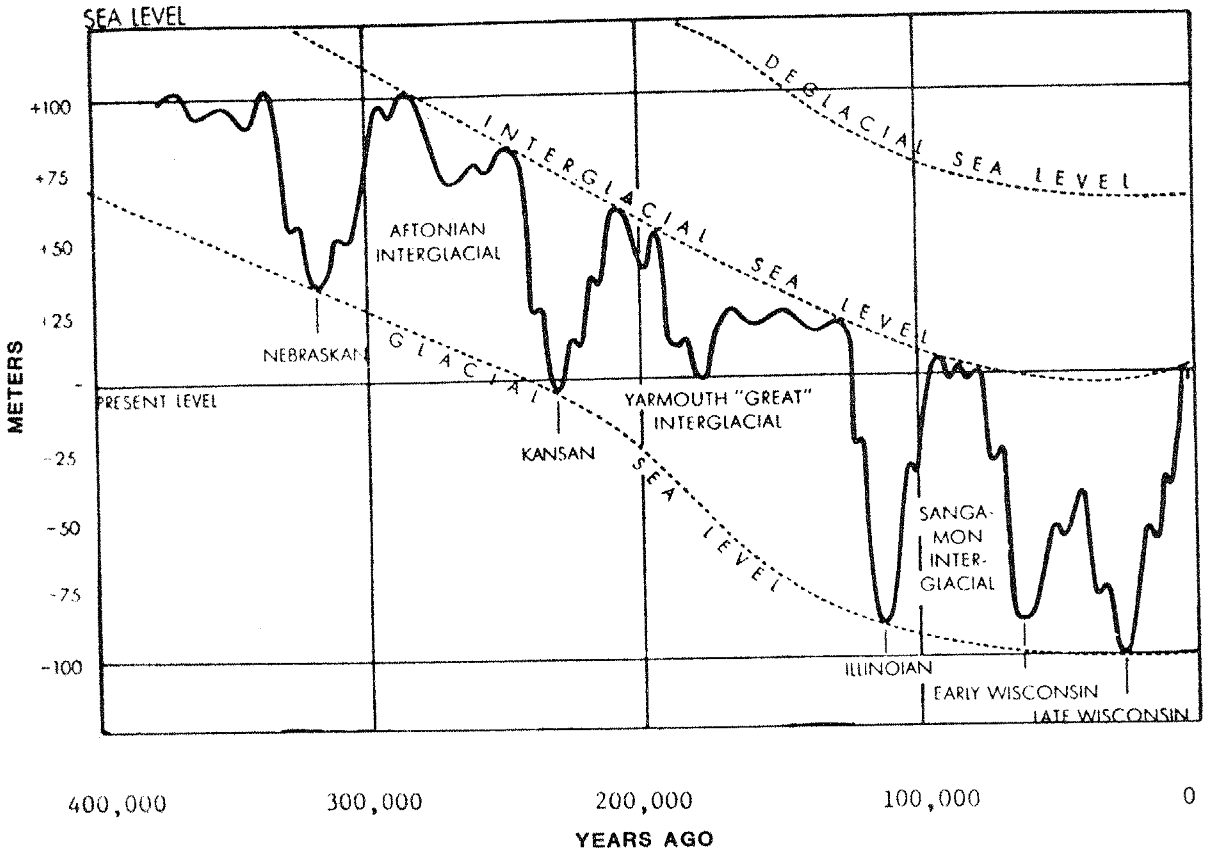


Figure 3. Quaternary changes of sea level (from Fairbridge 1960). Time scale is now considered to be 1-3 million years.

ice extended into the northern United States, resulting in a worldwide sea level about 100 m (330 ft) lower than present. The fact that coarse sands and gravels were deposited on the North Carolina Coastal Plain as cut and fill fluvial channel sediments suggests that the climate then was cold and wet. Such a subarctic climate would have produced minimal vegetative cover (Whitehead 1965, 1981), resulting in maximum surface water discharge and sediment erosion. The product of such an environment would have been coarse, sediment-choked, braided stream systems flowing across the Coastal Plain and discharging onto the Continental Shelf.

Sometime after 15,000 to 17,000 years B.P., the world climate began to warm again, the glacial ice masses began to melt and recede, and the present worldwide rise of sea level was underway (Fairbridge 1960; Whitehead 1981). The sedimentary and physical character of the present Albemarle Sound estuarine system was already defined. As the climate continued to warm, the vegetation slowly evolved into the hardwood and pine forests that characterize the Southeastern United States today, and the estuarine system migrated landward across the Continental Shelf to its present position.

1.3 SETTLEMENT HISTORY

Native Indians called Albemarle Sound Weapemeoc and lived in the area north of the sound (Figure 4) prior to the coming of European settlers. The sound was first explored by Sir Walter Raleigh's colonists under the leadership of Ralph Lane during the spring of 1586. Lane's Albemarle Sound expedition encountered hostile Indians, bad weather, and conflicts over

Figure 4. John White drawing of Indians fishing in the Albemarle region (from State Department of Archives and History, Raleigh, NC; printed by North Carolina Museum of History).

presumed rights. People in the four centuries since have had their own problems and conflicts, so that the present Albemarle Sound is a product and continuation of its history of water quality decline, fisheries limitations, eroding shores, transportation barriers, and poverty (Stick 1982).

European settlement began less than a century after Lane's expedition when settlers began moving south from Virginia. They built homesteads along the shores, produced crops for export, and sailed their crafts from sound to sea through the inlets of Currituck and Roanoke. Throughout the 17th century, Albemarle Sound was the hub and heart of North Carolina. Edenton, one of the colonial capitals, was the center of trade (Stick 1982). Herring from this area was one of the most important exports from the royal port of Edenton and was used as currency in the area (Street 1982).

Numerous communities and small towns were established on and near the water, and land was cleared in ever-increasing acreages for agriculture. Fishing thrived and the timber provided raw materials for local use and export. Timbering, fishing, boat building, and farming have been the main activities in the area since the 17th century (Stick 1982).

1.4 BIOLOGICAL ZONES

The Albemarle Sound estuary is characterized by low salinity, high turbidity, and shallow water. The central, deep portion of the estuary has a muddy bottom while the shallow, near-shore areas are sandy (Giese et al. 1979). Near the shore there are frequently stands of widgeon grass (*Ruppia* sp.) and other attached freshwater vegetation that support periphytic algae and associated animals, such as rotifers, nematodes, arthropods, and crustaceans.

Salinity in Albemarle Sound is generally less than 5 ppt, which dictates brackish to freshwater biological communities. As is typical of an oligohaline estuary, the benthic community is dominated by *Rangia* clams (Copeland et al. 1974b). The estuary serves as an important pathway and habitat for several anadromous fish that are important both commercially and recreationally in North Carolina.

Albemarle Sound is not directly connected to the ocean, but saltwater intrusion occurs gradually through Oregon Inlet by way of Croatan and Roanoke Sounds. The tidal amplitude is low and, consequently, there is little direct exchange with, or flushing by, the ocean. A large freshwater inflow in relation to the volume of the sound perpetuates a nearly freshwater biological environment (Giese et al. 1979). Dissolved oxygen levels are adequate to support biological communities in Albemarle Sound year-round (Bowden and Hobbie 1977); little or no anoxia has been reported in the estuary because of shallow depths and almost constant wind action. Thus, benthic communities remain established year-round in Albemarle Sound, in contrast to other North Carolina estuaries such as the Pamlico River Estuary (Copeland et al. 1983).

1.5 COMPARISONS TO OTHER ESTUARIES

With a large freshwater inflow/sound volume ratio (see Section 2.5), Albemarle Sound is intermittently brackish throughout its entire area and as such represents an estuarine system unique to North Carolina and the east coast of the United States. Albemarle Sound is an extensive permanent oligohaline system with large imports and exports of materials, turbid waters, and annual large spring freshwater inflows (Copeland et al. 1974b). Other oligohaline estuarine ecosystems along the east coast are usually found only in the upper reaches of Coastal Plain estuaries such as the Chesapeake Bay tributaries and the Pamlico River, Neuse River, and Newport River Estuaries of North Carolina (Brower et al. 1976).

Other extensive oligohaline estuaries exist on the west coast and gulf coast of the United States as well as in other areas of the world. An estuary on the west coast roughly comparable to Albemarle Sound in terms of its salinity regime is the Suisun Estuary at the mouths of the Sacramento and San Joaquin Rivers in California (Kelley 1966; Turner and Kelley

1966; Painter 1966a, 1966b). The Suisun estu-arine biota is functionally similar to that of Albemarle Sound, although the species present differ.

Lake Pontchartrain on the Louisiana gulf coast is another well-known and well-studied oligohaline estuary. Like the sound, Lake Pontchartrain is dominated by large freshwater inflows and food chains based on organic detritus (Darnell 1958, 1961; Fairbanks 1963; Kolb and van Lopik 1966; Stone 1980). The trophic structure of the Lake Pontchartrain Estuary appears to be very similar to that suggested for Albemarle Sound.

A third example of the oligohaline estuarine system useful for comparison to Albemarle Sound is the Baltic Sea (Zenkevitch 1963). In contrast to Albemarle Sound and other oligohaline systems of the United States, the Baltic Sea is rather deep, yet distinctly oligohaline. The zonation and types of plants and animals in the northwest section (Gulf of Bothnia) and northeast arm (Gulf of Finland) resemble the characteristic ecosystem of oligohaline estuaries like Albemarle Sound.

As we shall see in the following chapters of this profile, many aspects of the biology and ecology of Albemarle Sound are still unstudied. In lieu of quantitative and qualitative information on many biological components of the sound, information from published studies on the estuaries named above may prove useful at present to bridge these information gaps.

1.6 POTENTIAL CONFLICTS AND IMPACTS

Since Albemarle Sound is dominated by the flow of its tributaries, any activity on those river systems greatly influences what happens in the estuary. Thus, land-use patterns along the river basins and municipalities within the watershed may have adverse impacts on activities in the estuary. Nutrient inputs into the Chowan River are already notorious for their role in the perpetuation of a blue-green algal bloom there (Bond et al. 1978).

Much of the fresh water entering Albemarle Sound has its origins in the swamps and forests along the shores of tributaries. This water typically has a low pH and a high dissolved organic content. Fresh water entering the sound also contains a largely undetermined load of pesticides, heavy metals, and exotic organics, which, by adsorption onto particulate material in the water column, may lead to accumulations of these materials in the sound.

Reduction and alteration of flow rates by upstream reservoirs on the tributaries of Albemarle Sound could have far-reaching impacts on the migratory movements of anadromous fish and on nutrient cycling in the estuary. The untimely inputs of water from drainage canals could also alter the salinity and nutrient patterns of the sound.

The development of low-lying land surrounding the estuary, combined with high water tables, contributes to the potential of septic tank effluent contamination in Albemarle Sound. Contamination by bacteria from the digestive tracts of warm-blooded animals potentially threatens the shellfish beds of the estuary and could, in some localized areas, impact the quality of water for recreational uses as well. Indeed, a good portion of Albemarle Sound is closed today to commercial shellfishing because of bacterial contamination (see Section 3.3 for explanation).

Another potential conflict is the proposal by local interests to develop an inlet through the northernmost barrier island (Currituck Banks) to more directly connect Albemarle Sound to the ocean. There is a history of inlet openings and closings on the Outer Banks (Stick 1982), which have caused changes in salinity patterns and flushing characteristics. If an inlet could be maintained now, there would be a trade-off between the present biological community and the community that would evolve in response to increased salinities in the lower reaches of Albemarle Sound.

CHAPTER 2

DESCRIPTION OF THE ENVIRONMENT

2.1 REGIONAL GEOLOGY

Albemarle Sound lies in the Pamlico Terrace, an extensive, low, flat plain east of the Suffolk Scarp (Figure 5). The terrace slopes from 3 to 5 m (10 to 16 ft) elevations at the base of the scarp gently eastward to 0.3 to 0.6 m (1 to 2 ft) elevations at the end of the land peninsulas. The Suffolk Scarp, a relict shoreline, separates the Pamlico Terrace of the main estuarine region from the higher (up to 12 m or 39 ft) inland Coastal Plain (Talbot Terrace) around the westernmost segment of the Albemarle Sound system (Figure 5). The nature of each portion of the estuarine system and its associated geometry and bottom characteristics is determined by the mineralogic composition and the textural characteristics of the Pleistocene or older sediments (Bellis et al. 1975).

Streams in this area have relatively small sediment loading. Suspended sediments are mixed with organic sediments derived from the swamp forests and marshes to produce the dominant bottom sediment of Albemarle Sound. This brown-to-black sediment contains up to 15% organic matter (Giese et al. 1979) and is deposited within the standing waters of the embayed estuaries.

The central portions of Albemarle Sound and the adjacent embayed lateral estuaries are flat-bottomed with average water depths between 2 and 4 m (6.5 and 13 ft). Brown-to-black, organic-rich muds predominate but grade laterally into a thin apron of fine sand in the shallow waters around the perimeters of most of the estuaries (Figure 6) (Folger 1972; Giese et al. 1979). The sand apron generally occurs landward of the main break

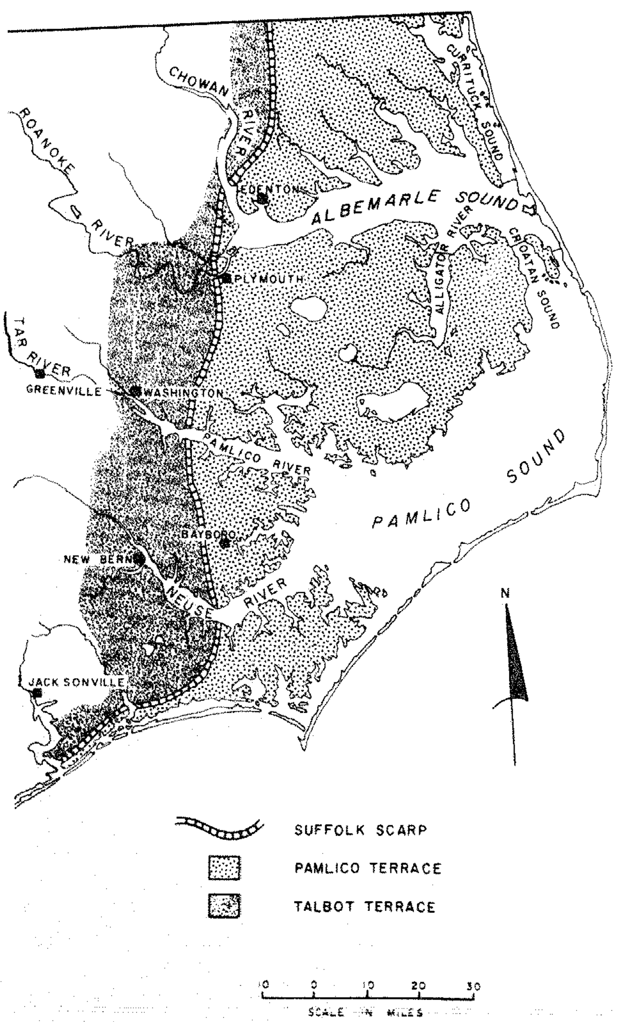


Figure 5. Geological features of the North Carolina Coastal Plain.

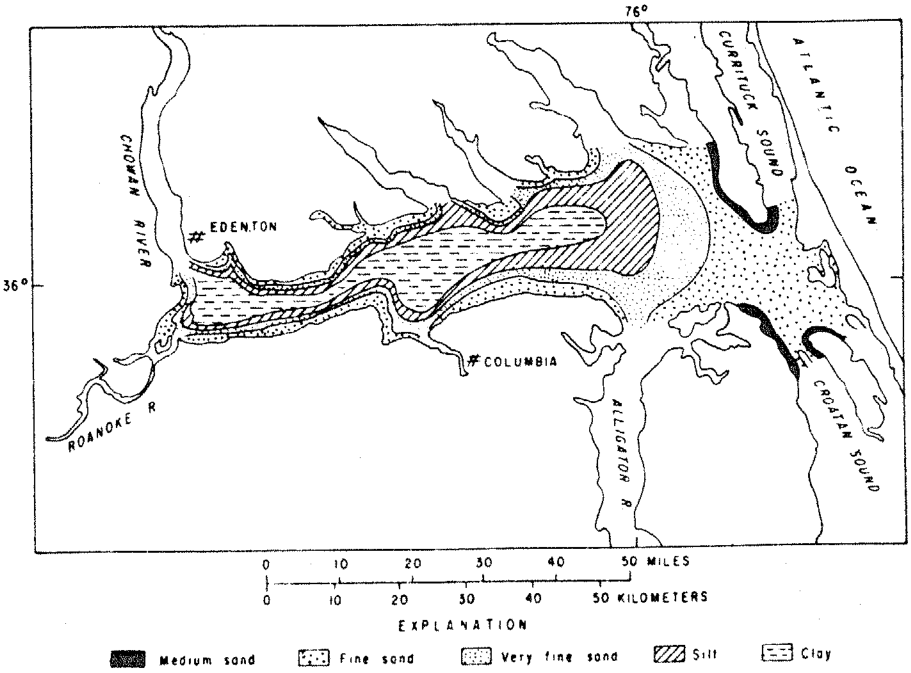


Figure 6. Texture of bottom sediments in Albemarle Sound (from Giese et al. 1979).

in bottom slope, at a depth of about 1 m (3 ft), and extends to the shoreline. Since the only major source of sand in the estuaries is from the erosion of the sediment bank shorelines, the distribution of sand is directly related to the location, size, composition, and rate of erosion of the sediment banks. The sediments in front of the marshes generally have little sand. They are characterized by high organic contents and contain peat blocks, logs, and stumps.

2.2 SHORELINE CHARACTERISTICS

The main estuarine shorelines of Bertie, Camden, Chowan, Pasquotank, Perquimans, and Washington Counties, along with the western shore of mainland Currituck County and the Albemarle Sound shoreline of Tyrrell County, are considered to be within the Albemarle estuarine system. This system is characterized by five types of shorelines: marsh, low bank, high bank, bluff, and swamp forest. The extent and distribution of the five shoreline types for those counties are shown in Table 2.

Marshes

Marshes (Figure 7a) are not a prominent shoreline type (8%) in the Albemarle Sound estuarine system; margins of the eastern embayed lateral estuaries sometimes contain localized, narrow, fringing marshes in front of the sediment banks. Most marsh is restricted to the outer Albemarle area, in eastern Camden, Currituck, and Dare Counties. The prevalence of the marsh shoreline increases dramatically southeastward into the Dar County area adjacent to Croatan and Roanoke Sounds, where the elevation and slope of the land are low and the estuarine waters become saline. The extensive marshes of the outer Albemarle area generally have the following characteristics:

1. several species of marsh grasses, predominantly black needlerush (Juncus roemerianus) with lesser amounts of several species of cordgrass (Spartina);
2. irregular shorelines consisting of coves and headlands, which range from a few meters to thousands of meters in width;

Table 2. Miles of shoreline types around the Albemarle Sound Estuary (date from Bellis et al. 1975).

County	Marsh	Low bank	High bank	Bluff	Swamp forest	Subtotal
Bertie	0	8	9	4	11	32
Camden	8	25	0	0	13	46
Chowan	0	8	14	1	29	52
Currituck	15	11	2	0	5	33
Pasquotank	1	36	4	0	6	47
Perquimans	1	22	24	0	15	62
Tyrrell	2	27	1	0	11	41
Washington	0	7	5	0	9	21
Total	27	144	59	5	99	334
Percent	8%	43%	18%	1%	30%	

3. marsh peats, which are thickest on the outer edge and thinnest on the inside where they lap onto the upland forests;

4. vertical scarps on the outer perimeter of the marsh shelf, which drop abruptly into 0.3 to 2 m (1 to 6.5 ft) of water; and

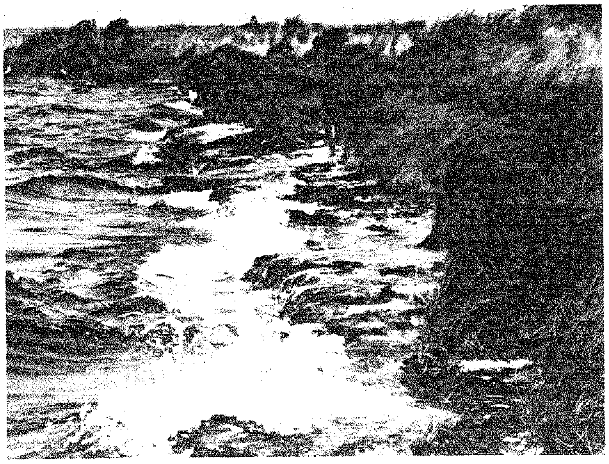
5. rapid rates of erosion averaging 1 m/yr (3 ft/yr) due to the large fetch in the outer estuarine areas (Bellis et al. 1975).

The marsh substrates are oxygen-deficient, water-saturated, organic peats mixed with varying amounts of inorganic sediment trapped by the baffling effects of grass stems during storm tides. Below the surface is a 25-to-50-cm (10-to-20-inch) thick live root zone. This tough, intertwined root mat is underlain by a zone of soft, decayed, clayey peat containing abundant logs and stumps on top of the old upland soil profile. As the marsh edge is attacked by wave action and organisms, the soft peat is undercut, large blocks slump, break off, and sink to the bottom where they are further broken down into fine organic detritus. This organic detritus is either redeposited with estuarine sediments along the marsh or is incorporated into the estuarine food chain (Benton 1979).

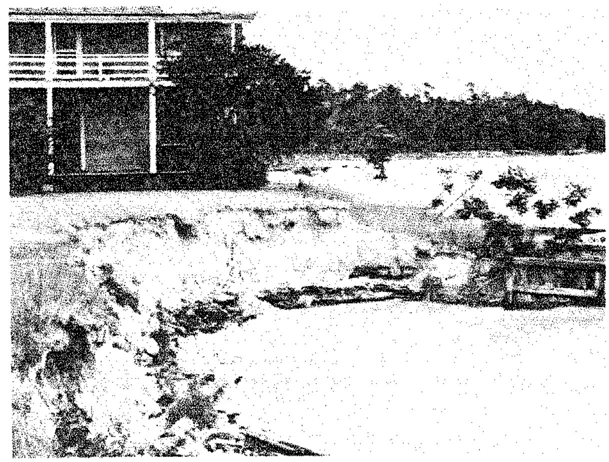
Marsh peats grow vertically and laterally in response to rising sea level, which is about 10 to 25 cm (4 to 10 inches) per century in Albemarle Sound (Fairbridge 1960; Giese et al. 1979). The rising water table causes increased stress on the adjacent upland forests, resulting in the gradual succession from forest to marsh and the burying of the upland soil profile and fallen trees. The landward extent of these marshes is limited in the Albemarle Sound Estuary by the height of flooding caused by regular astronomical tides or by irregular wind tides and the topography of the land. Thus, marshes are being eroded along their outer perimeter more than they are able to expand inland (Bellis et al. 1975).

Low Banks

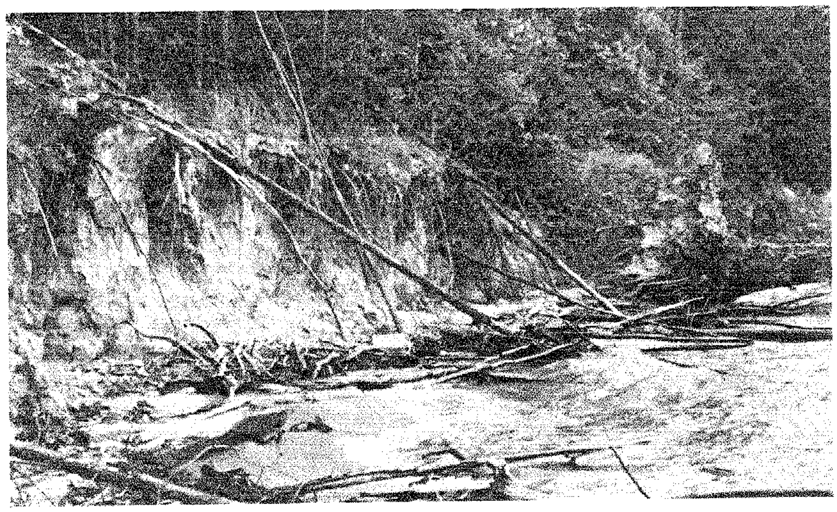
Low banks (Figure 7b) are the single most abundant shoreline type (43%) in the Albemarle system and are particularly important in Camden (54%), Pasquotank (76%), and Tyrrell (66%) Counties. Low bank shorelines are sediment banks composed of sand and clay and have a relief of 0.3 to 2 m (1 to 6.5 ft) above mean water level. The beach at the base of the eroded low bank usually consists of a thin and sporadic sand or clayey sand sediment layer on top of a clay bed that occurs at or slightly below the water line. This clay bed usually extends into the offshore



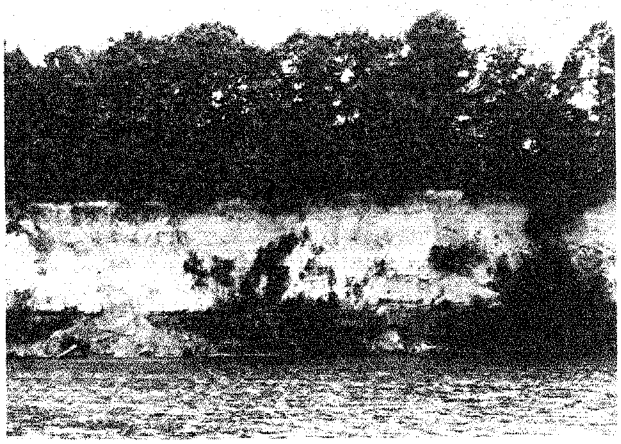
a. Marsh shoreline.



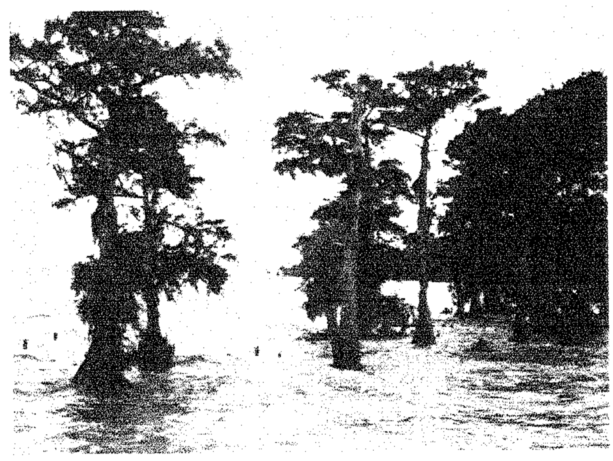
b. Low bank shoreline.



c. High bank shoreline.



d. Bluff shoreline.



e. Swamp forest shoreline.

Figure 7. Types of shorelines characterizing the Albemarle Sound estuarine system.

area and its resistance to erosion largely determines the bottom slope and water depths. Low bank shorelines are generally erosional with an average erosion rate of about 0.7 m/yr (2.3 ft/yr) and a range of 0 to 4 m/yr (0 to 13 ft/yr) (Bellis et al. 1975). The soft sand sediments that generally constitute the low banks are especially vulnerable to direct wave attack. When a major sand beach and bank vegetation are absent, a moderate wind tide or storm causes the waves to break directly on the bank. This action supplies new sand for a temporary beach. The new sand may also be trapped by bank vegetation that falls into the water and forms natural groins. These natural baffles trap and hold the new sediment and locally form extensive sand shoals. Occasionally, marsh grasses or other types of shrub vegetation become established and produce a fringing marsh. The presence of sand beaches, sand shoals, dead trees and brush, and fringing vegetation absorb the wave energy, decreasing the rate of shoreline recession. Most of these features in the Albemarle Sound area, however, are only short-lived because of the high energy of wind-driven water.

High Banks

High bank shorelines (Figure 7c) are composed of sand and clay sediments, have a relief of 2 to 6 m (6.5 to 20 ft) above mean water level, and constitute about 18% of the total shoreline miles. The high banks generally occur in the western half of the Albemarle estuarine system, primarily in Bertie (28%), Chowan (27%), Perquimans (39%), and Washington (24%) Counties. These shorelines have an average erosion rate of 0.6 m/yr (2 ft/yr) with a average range of 0 to 4 m/yr (0 to 13 ft). The banks composed of uncemented sands are the most susceptible to erosion, while those composed of tight clays cemented by iron compounds are more resistant. Where the more resistant beds occur in the high banks, they constitute the lower 1.5 to 2.5 m (5 to 8 ft) of the bank and are overlain by a bed of clean quartz sand. Where the overlying sand beds are surface aquifers, they are characterized by extensive slumping and caving of the sand units. High banks are generally eroded during severe storms when onshore waves overtop the sand beach and break directly on the base of the bank. As the bank becomes more undercut, the unstable overhang eventually collapses onto the beach. These fresh sediments are reworked by the waves and temporarily broaden and stabilize the beach with a new layer of sand. Fallen trees and brush act as natural groins and temporarily help stabilize the beach. As with low banks, if vegetation of any form can become established either on the beach or on the bank, it will absorb much of the wave energy and decrease the rate and extent of shoreline recession (Bellis et al. 1975).

Bluffs

Bluff shorelines (Figure 7d) are sediment banks composed of sand and clay that have a relief greater than 6 m (20 ft) above mean water level (Bellis et al. 1975). These spectacular shorelines constitute about 1% of the Albemarle Sound system and only occur along the Chowan River and the westernmost end of Albemarle Sound in Bertie (12%) and Chowan (2%) Counties. The bluffs occur where the northeast-trending Suffolk Scarp and the Talbot Terrace intersect Albemarle Sound in southeastern Bertie County and then cross the Chowan River into northern Chowan County. Bluffs generally consist of tight clay and moderately to tightly cemented sandstone at the base with unconsolidated water-bearing sands and clayey sands on top.

The bluffs are generally receding at the average rate of 0.75 m/yr (2.5 ft/yr) with a range of 0 to 2.5 m/yr (0 to 8.2 ft/yr) year. Where groundwater seeps out on top of the impermeable clays, the bluffs slump onto the beaches below, carrying large blocks of sediment with their surface vegetative cover. Such slump blocks are then reworked by the waves producing new sediment for the beach and temporarily stabilizing it. The disintegrating blocks may develop a new vegetative cover that absorbs wave energy and decreases the rate and amount of shoreline recession.

Swamp Forests

Swamp forests (Figure 7e) are abundant in the Albemarle Sound Estuary, constituting 30% of the mapped shorelines

(Bellis et al. 1975). Swamp forests thrive in freshwater, but cannot tolerate more than brackish water salinities (i.e., 5 ppt). Persistent salinity-limiting conditions only occur in the easternmost part of the Sound in Dare County. Cypress-gum swamp forests occur primarily along the margins of the embayed lateral estuaries throughout the entire Albemarle system where the broad river floodplains are being inundated. The average rate of shoreline recession averages about 0.7 m/yr (2.3 ft) with a range of 0 and 2.5 m/yr (0 and 8.2 ft/yr). The shoreline recedes as the gum and maple are drowned out by permanent flooding. The more flood-tolerant bald cypress survives considerably longer and is left standing as scattered remnants in front of the swamp forest shoreline. The permanently flooded cypress become increasingly stressed and eventually die or are blown over by winds. If the cypress stand is dense, shoreline recession is negligible. If the cypress die or are logged, however, the gum-maple forest is eroded rapidly. All of these trees have shallow root systems, and once the roots are exposed through wave action, the trees are readily toppled. Sometimes it is difficult to distinguish the actual shoreline because the treeline does not necessarily follow the land-water interface.

Throughout the Albemarle system, numerous small tributary creeks enter the estuary. The juncture of the tributary with the estuary is typically characterized by a protruding headland of cypress that is more resistant to erosion than the adjacent sediment bank. These cypress headlands tend to segment what would otherwise be a uniformly retreating sediment bank into a repeated pattern of coves and headlands. The coves tend to retreat faster, but do act as basins or traps for the eroded sediments.

2.3 WATERSHED CHARACTERISTICS

The area surrounding Albemarle Sound is sparsely populated, reflecting its history. Although the rural population is projected to decline steadily, the total population of the area is expected to increase by about 20% over the next 50 years as the small communities grow in population.

About two-thirds of the land in the nine counties surrounding Albemarle Sound is forested (Table 3). The amount of land taken up by urban areas and highways is small; about 18,200 ha (45,000 acres) of the total of nearly 800,000 ha (2 million acres). All cities and towns around the sound are small, and none support a population of more than 20,000.

Land use in the lowlands surrounding Albemarle Sound is rapidly changing (Heath 1975). Although cultivated land in the State as a whole is decreasing in area, the number of acres under cultivation in the lowlands south of Albemarle Sound is increasing (Figures 8a and 8b). For example, nearly 12,000 ha (30,000 acres) of forested land in Tyrrell County have been converted to agricultural land since 1974 (McDonald and Ash 1981). Most of the mineral soils (Figure 9) have traditionally been farmed, but agriculture is now increasing in the shallow organic soils and in some of the deep organic soils.

Land use around Albemarle Sound remains limited by the low-lying swampy topography of the area. To effectively cultivate land of low elevation and high water tables, it must be extensively drained (Skaggs et al. 1980). With increasing agriculture, a network of canals carrying large amounts of freshwater to the estuary has been constructed. Although there are more canals today, they are not a recent innovation. Drainage was initiated in the late 1600's (Lilly 1981). A company owned by George Washington started the first large-scale drainage project on these soils in the 1790's. The latest period of increased drainage activity began in the early 1970's when several large corporations became involved in clearing and developing thousands of acres of land in eastern North Carolina (Figure 10). The general expense of draining the low-lying land will probably continue to limit the variety of land uses available to that area.

Underlying bedrock forms the environment groundwater. The Piedmont and mountain regions of North Carolina are underlain by bedrock relatively close to the

Table 3. Land area and land use (in acres) around the Albemarle Sound Estuary (North Carolina Conservation Need Inventory 1971).

County	Total	Federal non-crop	Urban etc.	Crop land	Pasture	Forest	Other
Bertie	443,520	0	13,277	94,234	6,116	309,083	17,970
Camden	152,960	245	1,900	38,570	444	107,319	4,102
Chowan	115,200	35	1,900	36,312	2,200	64,657	7,231
Currituck	174,720	6,200	2,500	40,876	2,000	83,270	37,274
Dare	248,320	22,045	6,100	142	100	184,872	33,961
Pasquotank	146,560	865	5,000	54,089	3,000	78,228	4,889
Perquimans	167,040	1,300	3,309	57,901	4,393	95,560	4,072
Tyrrell	255,360	0	2,220	22,828	1,900	216,932	10,480
Washington	215,040	2,450	6,488	61,000	5,636	113,811	15,303
Total	1,918,720	33,140	45,159	405,952	25,789	1,263,732	135,282

surface, but in the Coastal Plains bedrock is covered by unconsolidated sedimentary deposits that range in thickness from a few meters along the fall line to about 3,000 m (9800 ft) at Cape Hatteras (Heath 1980). These deposits form the groundwater aquifers for the Coastal Plain (Figure 11).

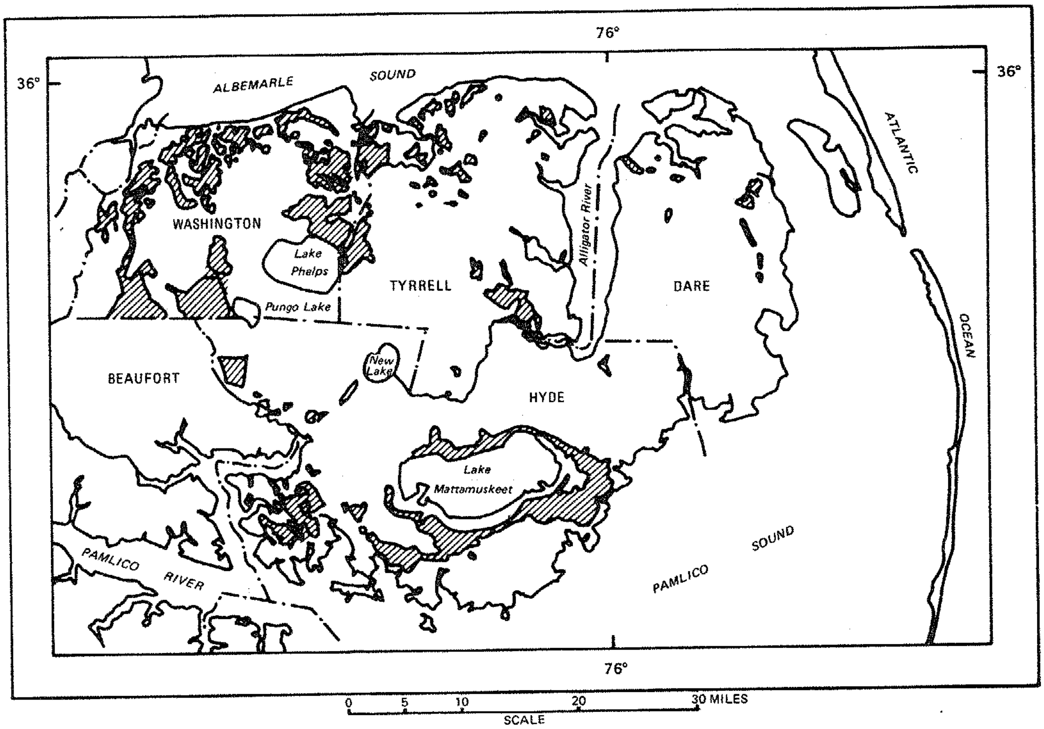
The two most important aquifers in the Coastal Plain are the upper aquifer and the limestone aquifer (Heath 1980). The upper aquifer yields the most water (Figure 12) and is a source of input to the streams and the estuary. This upper aquifer is also most apt to be contaminated by land-use activities. The water table from this aquifer lies close to the surface in much of the low-lying areas around the Albemarle Sound. The limestone aquifer, or Castle Hayne formation, is the most productive aquifer in North Carolina in terms of yields to individual wells. The amount of groundwater available from both aquifers is limited to the amount of water that can be drawn from storage, the natural discharge that can be intercepted, and the additional recharge that can be induced into the aquifer (Wilder et al. 1978).

Wilder et al. (1978) traced the fates and distribution of precipitation over the estuary and its watershed in northeastern North Carolina (Figure 13). Only about 10% of the total precipitation runs overland to the receiving streams. Another 20%, however, enters the receiving stream through runoff into the groundwater and then into the stream. Finally, only about 2% of the total precipitation flows as a recharge to the groundwater reservoir.

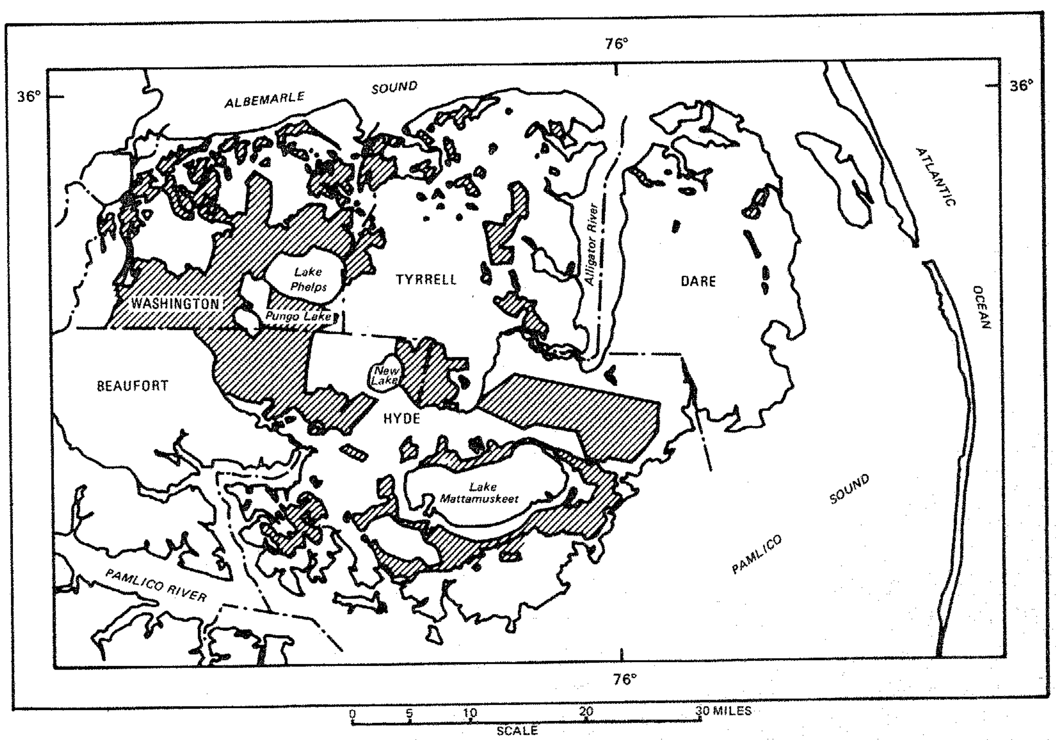
2.4 CLIMATE

Albemarle Sound and northeastern North Carolina generally receive between 119 to 130 cm (47 to 51 inches) of rain per year (Figure 14). These figures can vary greatly from place to place and over time. Rainfall during dry years may be as low as 89 cm (35 inches) and in wet years as high as 200 cm (79 inches) (Wilder et al. 1978). Distribution of rainfall throughout the year is reasonably uniform. The highest precipitation is associated with thunderstorms in the summer (Figure 15). The lowest rainfall occurs during the fall, with a secondary low during the spring.

Evapotranspiration losses tend to be much more constant from year to year than is rainfall (Wilder et al. 1978). Therefore, the variations in annual rainfall result in significant differences in the amount of rainfall available to replenish water removed from the groundwater and to flow into the estuary. Evapotranspiration



a. Cultivated land in 1956.



b. Cleared land in 1973.

Figure 8. Changes in land use on the Pamlico - Albemarle Peninsula (from Heath 1975).

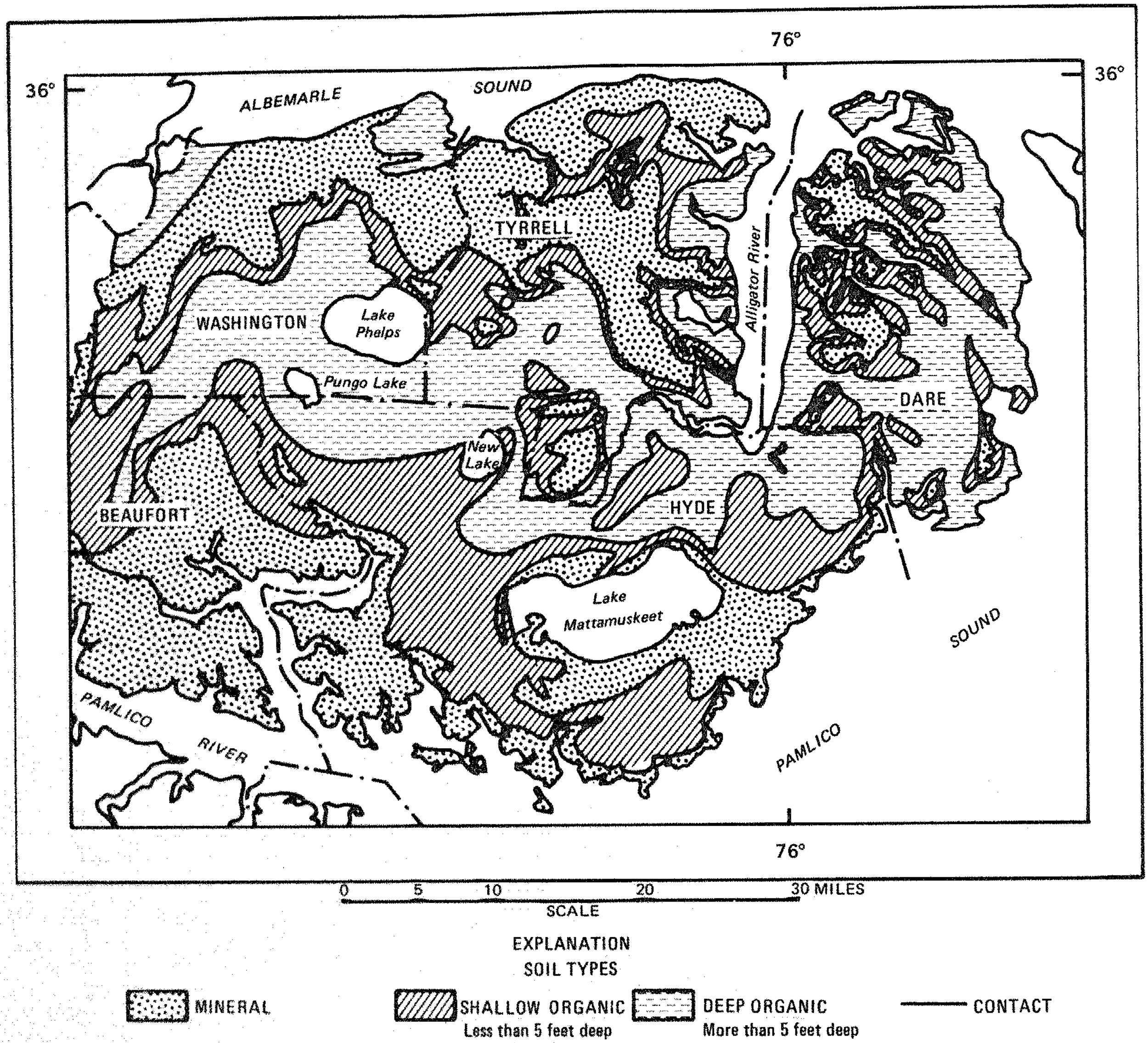


Figure 9. Generalized soils map (from Heath 1975).

exceeds rainfall in the average year during the months of May and June (Figure 15). During dry years, evapotranspiration may exceed rainfall all year.

Albemarle Sound lies in a belt where the average January temperature is between 6° and 8°C (43° and 46°F) (Clay et al. 1975). Temperatures seldom fall below -12°C (10°F), and the winters are mild. Summers are characterized by hot, humid days, with the average daytime temperature reaching 32°C (90°F) or above in July and August.

Wind directions change frequently in the area of the estuary, but the prevailing winds are from the S-SW and have an average speed of 15 to 16 km/hr (9 to 10 mph) (Clay et al. 1975). Under typical weather conditions the highest wind velocities (N-NW during frontal movements) generally occur in winter, and the lowest wind velocities occur during the summer. However, localized or isolated thunderstorms, hurricanes, and tornadoes may create winds having major impacts during the summer.

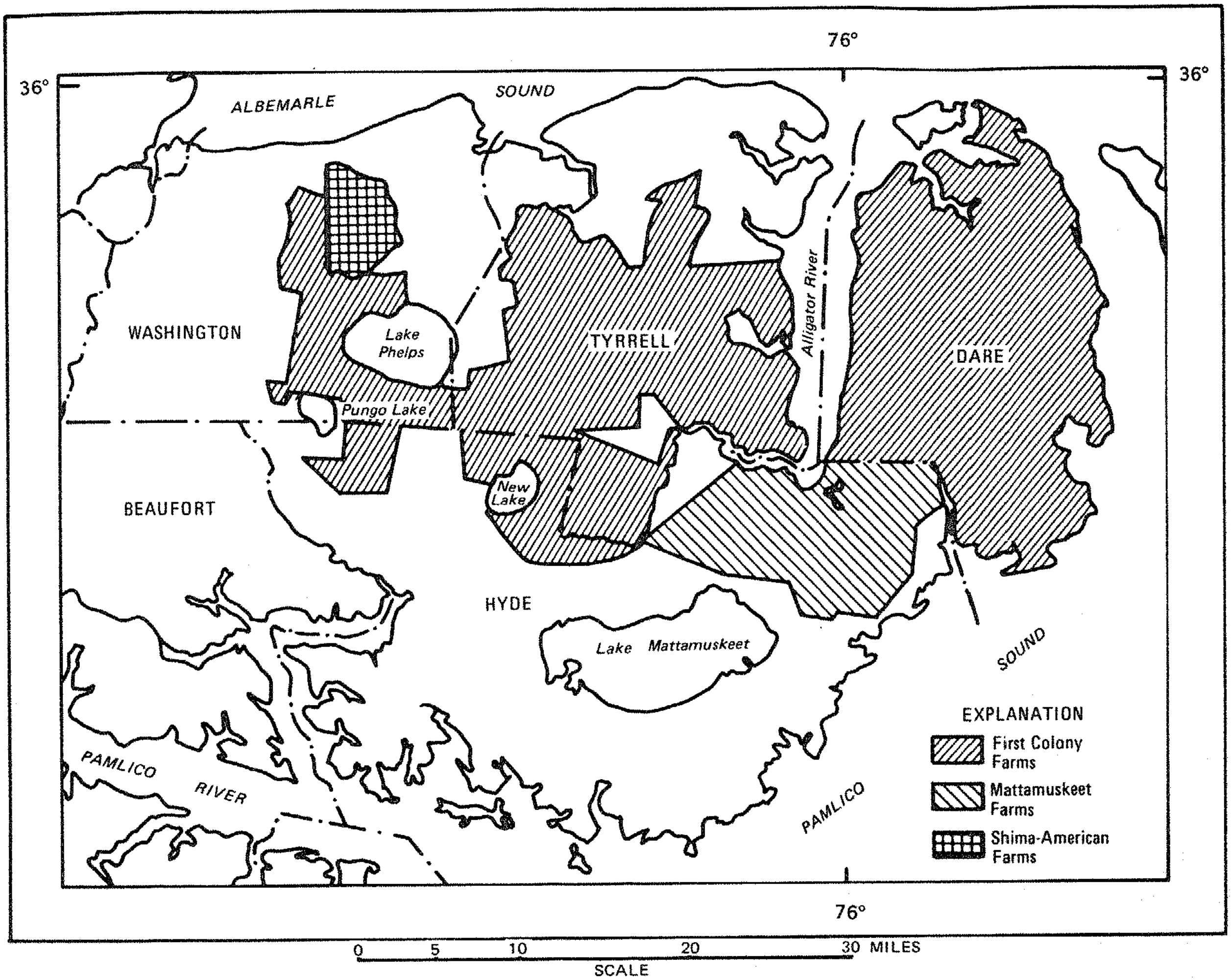


Figure 10. Land owned by corporate farms in 1974 (from Heath 1975).

2.5 HYDROLOGY

The two major sources of freshwater into Albemarle Sound are the Chowan and Roanoke River (Giese et al. 1979). The average annual inflow of freshwater to Albemarle Sound is approximately 17,000 cubic feet per second (cfs) (Table 4). Over half that (8,800 cfs) is from the Roanoke River. The net inflow from the rivers entering Albemarle Sound other than the Chowan and Roanoke is about equal to the amount of water entering the sound by precipitation.

Runoff, and therefore freshwater input, is not evenly distributed throughout a year and may be far less than average for several months at a time (Wilder et al. 1978). The amount of runoff is highest during the late winter and early spring and lowest during the fall (Figure 16).

Before impoundments were constructed on the Roanoke River, its normal flow rate was highest in winter and lowest in summer and fall (Table 5). Comparing the mean discharge prior to impoundment (Table 5) with the water budget calculated for the river after impoundment (Table 4) indicates that the average flow rates in winter are slightly reduced, and the average flow rates in summer are slightly increased. The mean annual discharge of the Roanoke River over a 37-yr period (Table 6) ranges between about 5,300 cfs in a dry year to almost 12,000 cfs during

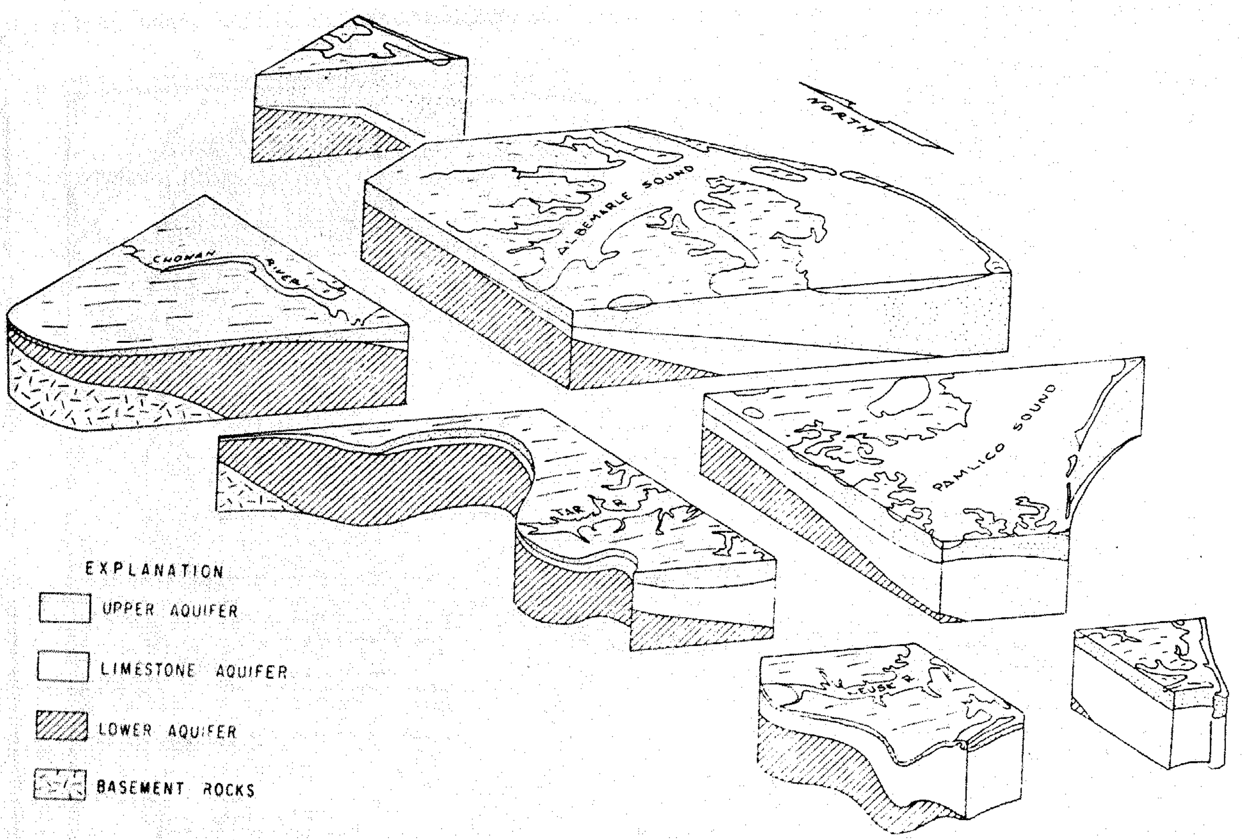


Figure 11. Generalized block diagrams of northeastern North Carolina showing the upper 300 m (1,000 ft) of the underlying aquifer (from Wilder et al. 1978).

a wet year. While these data are for the Roanoke River, other tributaries of Albemarle Sound tend to follow the same year-to-year and seasonal patterns.

Wind is the most important factor influencing short-term circulation and water levels in Albemarle Sound, with tides and freshwater inflows from tributaries playing a secondary role (Geise et al. 1979). Easterly winds will cause low water levels in the eastern end of the sound and high water levels in the western end of the Sound; westerly winds usually have the opposite effect. Northerly winds tend to build the water level up along the southern shore and reduce the water level along the northern shore, with the converse true for southerly winds (Figure 17). The sound is less responsive to wind tides than the embayed lateral tributaries, which occasionally may be almost emptied by winds blowing downstream. Compared to their influence in estuaries in southeastern North Carolina and Chesapeake Bay, lunar tides are of much less importance in Albemarle Sound.

Because of the shallowness and long fetch of the basin, wind and wave action eliminates vertical stratification except under certain calm conditions. The average depth is about 3.5 m (11.5 ft), the deepest portion is almost 9 m (30 ft), and most of the central area of the bay is little more than 6 m (20 ft) deep (Figure 18). The total volume of Albemarle Sound is about 5,310,000 acre-ft (Giese et al. 1979).

The total average outflow from Albemarle Sound (about 17,000 cfs) is larger relative to its volume (5,310,000 acre-ft) than its nearest counterpart, Pamlico Sound (32,000 cfs and 21,000,000 acre-feet). The average residence time of water in the sound is about 45 days. The current strength of the freshwater outflow

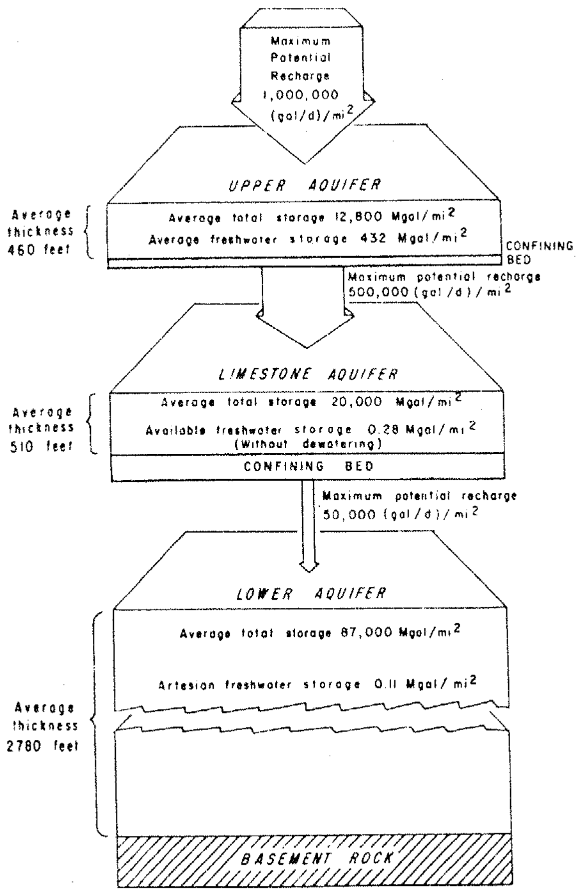


Figure 12. Estimated average amount of recharge to and storage in the three major aquifers underlying the Albemarle Sound Estuary (from Wilder et al. 1978).

is sufficient to effectively block saline water from the system. Moreover, the sea water that does reach Albemarle Sound has already been diluted to almost half strength in Pamlico Sound. Thus, the salinity in Albemarle Sound is always relatively low.

2.6 WETLAND AND AQUATIC ENVIRONMENTS

Wetlands around Albemarle Sound are generally classified as three types: swamp forest, pocosins, and irregularly flooded marshes (Cowardin et al. 1979). Mainly because of the lack of lunar tides, there are few acres of regularly flooded salt marsh around Albemarle Sound (Wilson 1962; Bellis et al. 1975). In surveys by Wilson

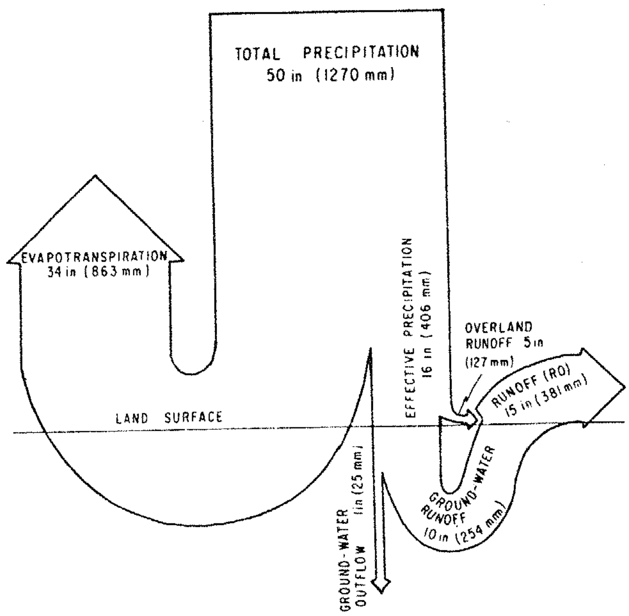


Figure 13. Components of the hydrologic cycle in northeastern North Carolina (from Wilder et al. 1978).

(1962) and Bellis et al. (1975), about 65% of the wetlands in counties surrounding Albemarle Sound is pocosins (Table 7).

Wooded swamps are characterized by long periods of standing water, although the forest floor may be dry during a portion of the growing season. The peaty or mucky soil supports hardwood trees characteristic of Southeastern United States floodplains. The three most common canopy trees are black gum (Nyssa sylvatica), tupelo gum (N. aquatica), and bald cypress (Taxodium distichum) in single stands or in combinations. Nutrient release in the wooded swamp is slow; most nutrients accumulate in the sediments (Woodwell 1958), which filter water flowing to the estuaries.

Pocosins are characterized by being flooded during the winter and waterlogged during the remainder of the year. Dominant vegetation in the pocosins are broad-leaved, evergreen shrubs and pond pine (Pinus serotina) (Richardson et al. 1981). The pocosin soil is low in nutrients and, as such, is probably not amenable to clearing and farming (Woodwell 1958). Pocosins lack the abundance or diversity of wildlife of wooded swamps (Richardson

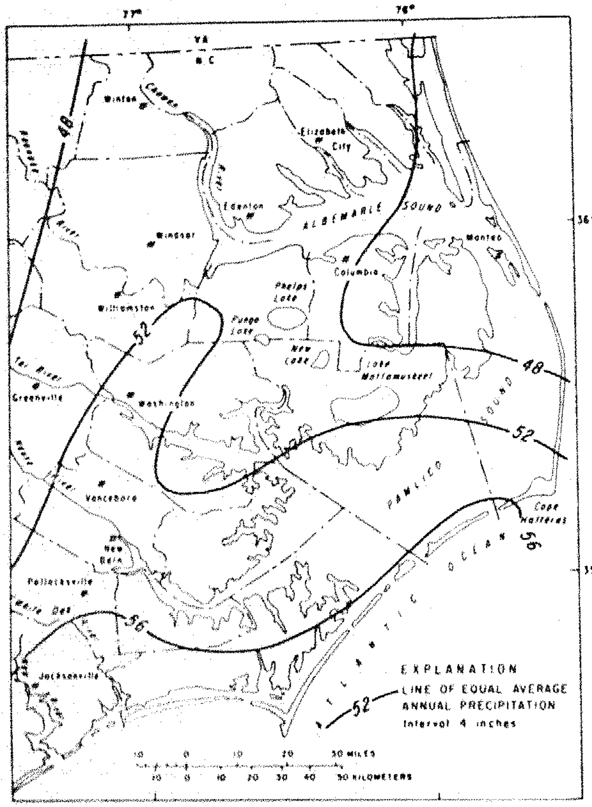


Figure 14. Average annual precipitation (inches) for northeastern North Carolina (from Wilder et al. 1978).

et al. 1981). Their major energetic contribution to the estuarine system may be through the export of organic matter when flood outlets exist.

Irregularly flooded salt marshes border the estuary along the shorelines of four of the nine counties (Table 7). These

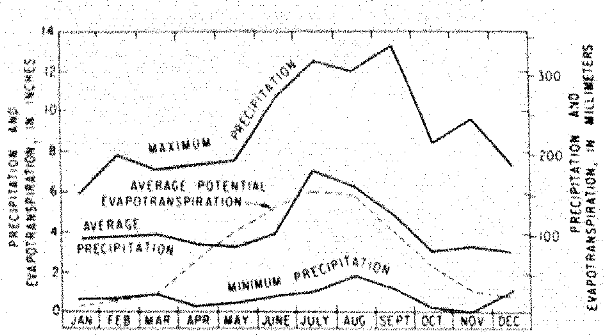


Figure 15. Maximum, average, and minimum monthly precipitation and calculated average evapotranspiration at Elizabeth City, NC, 1931-1960 (from Wilder et al. 1978).

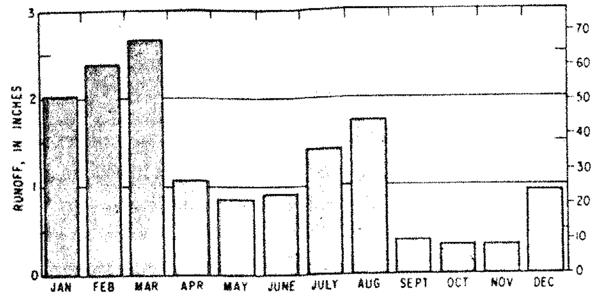


Figure 16. Average monthly runoff for streams draining the Albemarle region (from Wilder et al. 1978).

salt marshes are characterized in their lower elevations by the black needlerush (Juncus roemerianus) and in the higher locations by the salt meadow cord grass (Spartina patens) and salt grass (Distichlis spicata). Although there is considerable controversy as to the magnitude of contribution from the irregularly flooded salt marsh, it is thought to contribute organic matter to the estuary during times of large-scale flooding (Wilson 1962).

The Roanoke, Chowan, Perquimans, Little, Pasquotank, North, Alligator, and Scuppernong Rivers enter Albemarle Sound. This riverine system drains a total area of about 47,550 km^2 (18,359 mi^2) (Giese et al. 1979) and has an average annual outflow of about 17,000 cfs (Table 4). The outflow from these rivers is sufficient to effectively block saline water from the system, except during unusual drought conditions. Because the river basins are oversized for the amount of water they carry, water velocities are low.

The aquatic environment of Albemarle Sound is typically oligohaline (Heath 1975; Bowden and Hobbie 1977); i.e., 0.5-5 ppt (Cowardin et al. 1979). The average surface salinity of the Albemarle Sound Estuary does not normally exceed about 5 ppt (Figure 19), and it is generally lowest during the spring (Figure 20a) and highest during the fall (Figure 20b). Saltwater seldom penetrates the estuary up to the mouths of the Roanoke and Chowan Rivers (Bowden and Hobbie 1977; Giese et al. 1979). Due to the shallowness of the estuary and prevailing winds,

Table 4. Gross water budget (in cfs) for Albemarle Sound, based on 1965-1975 data (from Giese et al. 1979).

Month	Precipitation	Evaporation	Chowan inflow	Roanoke inflow	All other inflow	Net outflow
January	2,800	1,000	6,500	10,000	4,200	23,000
February	3,400	1,700	9,100	12,000	5,900	28,000
March	2,900	2,200	8,600	10,000	5,600	25,000
April	2,500	3,400	6,600	11,000	4,300	21,000
May	2,800	3,900	3,700	10,000	2,400	16,000
June	3,600	4,200	2,600	8,500	1,700	12,000
July	5,400	4,100	3,000	8,000	1,900	14,000
August	5,000	3,500	3,500	7,500	2,200	15,000
September	4,300	2,800	3,000	6,500	2,000	13,000
October	2,500	1,800	2,200	6,500	1,400	11,000
November	3,000	1,400	2,500	7,500	1,600	13,000
December	2,600	900	4,400	8,300	1,300	16,000
Average annual	3,400	2,600	4,600	8,800	2,900	17,000

Table 5. Monthly mean discharge (cfs) of the Roanoke River at Roanoke Rapids, NC, 1913-1949 (from U.S. Geological Survey data).

Month	Mean (cfs)
January	11,790
February	12,410
March	13,330
April	11,120
May	8,082
June	6,500
July	6,852
August	6,986
September	5,750
October	5,717
November	5,511
December	7,956

Table 6. Normal annual mean discharge (cfs) of the Roanoke River at Roanoke Rapids, NC, 1913-1949 (from the U.S. Geological Survey data).

Year	Mean (cfs)	Year	Mean (cfs)
		1931	5,279
1913	7,229	1932	5,297
1914	7,143	1933	9,231
1915	9,488	1934	6,884
1916	8,094	1935	9,944
1917	7,754	1936	11,920
1918	6,978	1937	11,300
1919	10,660	1938	10,840
1920	7,019	1939	9,151
1921	8,700	1940	9,700
1922	9,310	1941	6,250
1923	8,600	1942	5,909
1924	8,923	1943	8,975
1925	8,002	1944	8,092
1926	5,394	1945	9,982
1927	6,286	1946	9,138
1928	10,840	1947	6,566
1929	8,393	1948	9,929
1930	6,988	1949	11,990

Table 7. Approximate acres of wetlands by county in the vicinity of Albemarle Sound (from Wilson 1962).

County	Wooded swamps	Pocosins	Irregularly flooded marshes
Bertie	32,00	57,300	
Camden	46,000	28,900	1,600
Chowan	4,300	10,150	
Currituck	28,400	13,750	23,600
Dare	4,050	138,200	21,200
Pasquotank	22,100	27,200	
Perquimans	10,250	18,850	
Tyrrell	24,400	138,500	500
Washington	55,000	61,200	
Totals	226,500	494,050	46,950

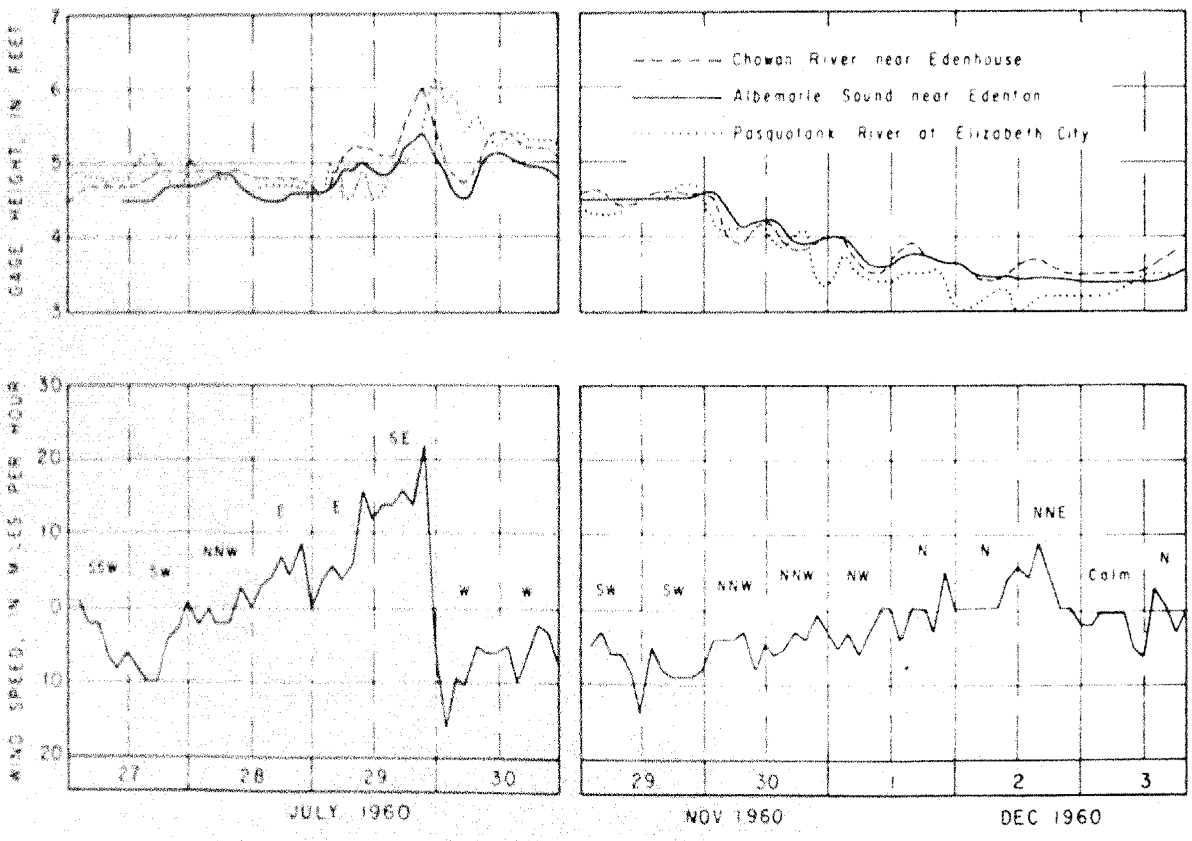


Figure 17. Wind speed and direction at Elizabeth City and water levels near Edenhouse, Edenton, and Elizabeth City during 1960 (from Giese et al. 1979).

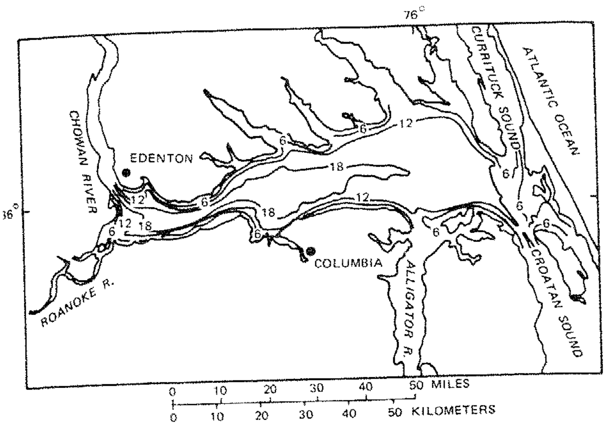


Figure 18. Depth profile (in feet) of Albemarle Sound (from Giese et al. 1979).

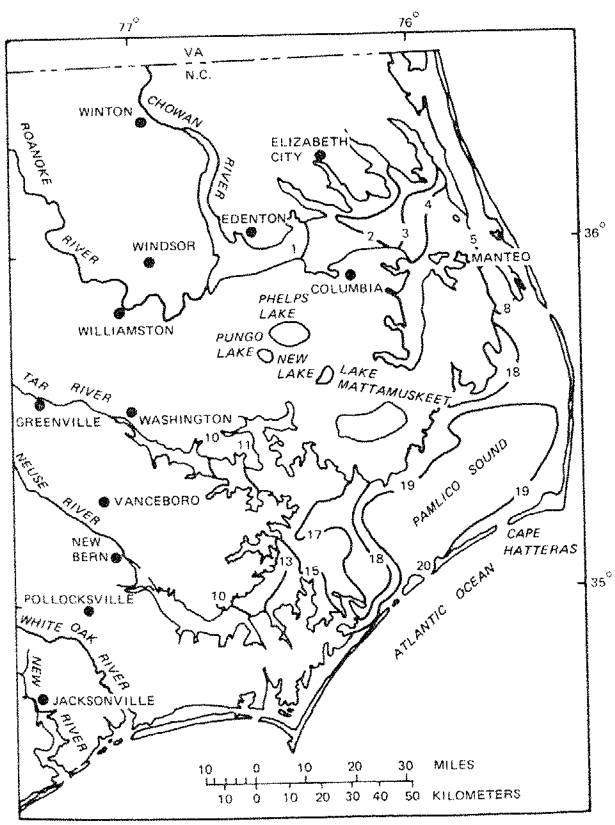


Figure 19. Average surface salinity in Albemarle Sound and vicinity during December (from Giese et al. 1979).

long-term stratification does not normally occur in Albemarle Sound.

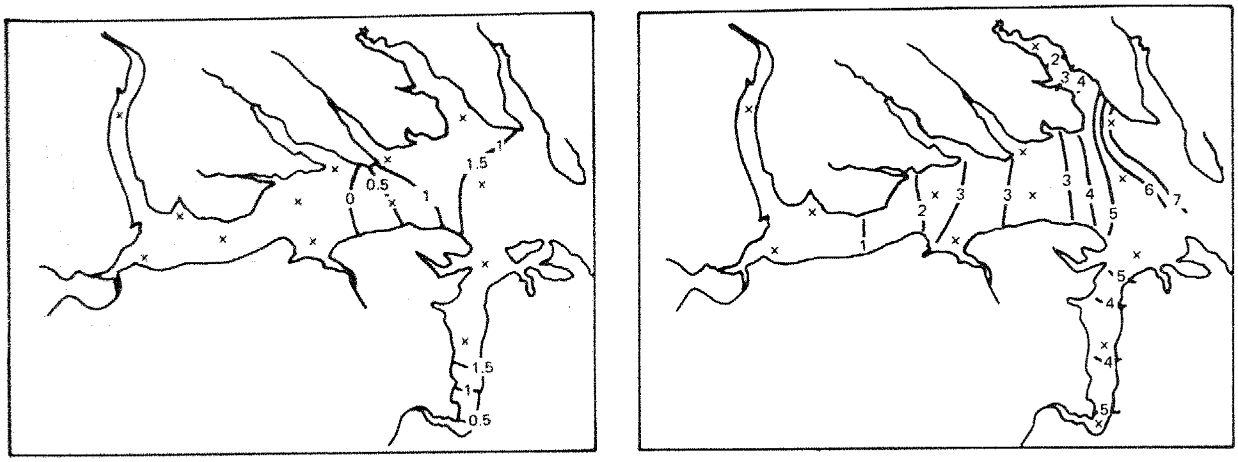
Mean monthly temperatures in the Albemarle Sound Estuary range between 5°C (41°F) during January to about 28°C (82°F) during July and August (Bowden and Hobbie 1977; Figure 21). The extremes in the estuary are as low as 0°C (32°F) and as high as 30°C (86°F) (Bowden and Hobbie 1977). Temperature is probably not a limiting factor for most organisms using Albemarle Sound Estuary.

Dissolved oxygen in Albemarle Sound apparently is adequate throughout most of the year. Concentrations range from about 4 ml of O_2 to about 9 ml of O_2 during all seasons of the year (Bowden and Hobbie 1977). Short-term dissolved oxygen depletion occasionally causes fish kills, especially in the Chowan River.

Since stratification is normally not an important factor in Albemarle Sound, there is usually relatively little difference between surface and bottom dissolved oxygen concentrations. Because of high benthic metabolism or decomposition rates in some localized areas, however, surface dissolved oxygen is occasionally significantly higher than the bottom dissolved oxygen (Bowden and Hobbie 1977). Low dissolved oxygen conditions are sometimes found in the Alligator River and Chowan River Estuaries (Bowden and Hobbie 1977). This is probably due to organic loading in these upper estuarine areas and the reduced circulation there during the summer. Occasional instances of supersaturation of oxygen in surface waters have been observed in Albemarle Sound.

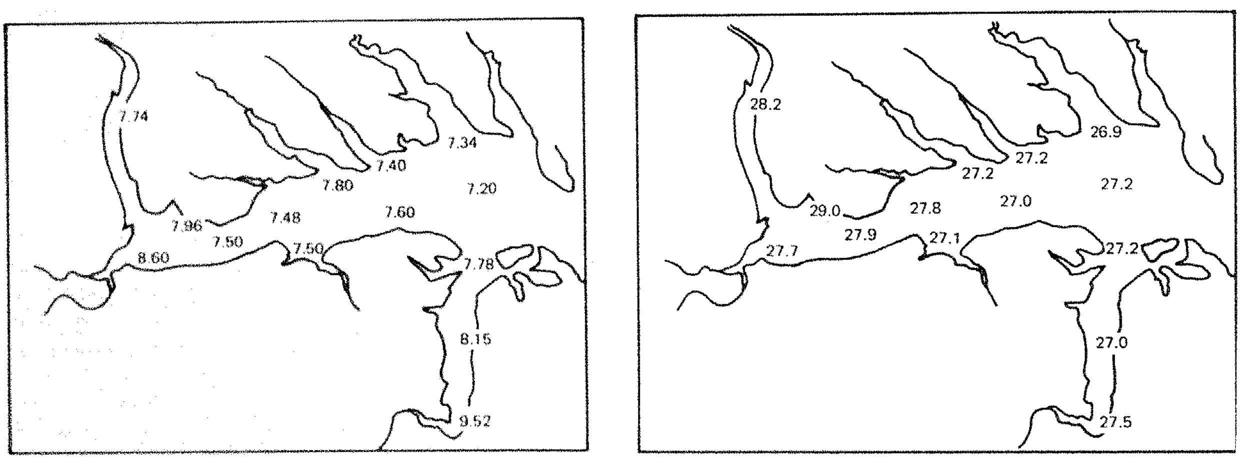
2.7 CHANGES IN SEA LEVEL

As pointed out in Section 2.2, sea level is rising at a rate of 1.0 to 2.5 mm/yr (4 to 10 inches per century). This small rise can have a major impact upon determining the nature of the Albemarle estuarine system. The consequence of the rising sea level is a general flooding of the land, first up the topographically low river valleys and then laterally across the uplands. As the land floods, the shoreline moves inland.



a. 7 April 1971. b. 12 November 1970.

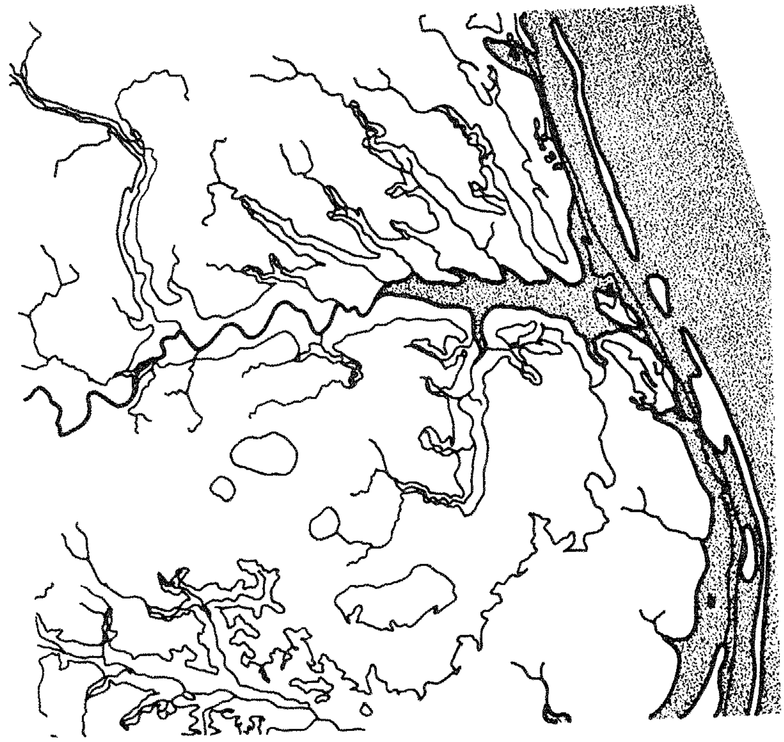
Figure 20. Surface salinity (ppt) in Albemarle Sound during April 1971 and November 1970 (from Bowden and Hobbie 1977).



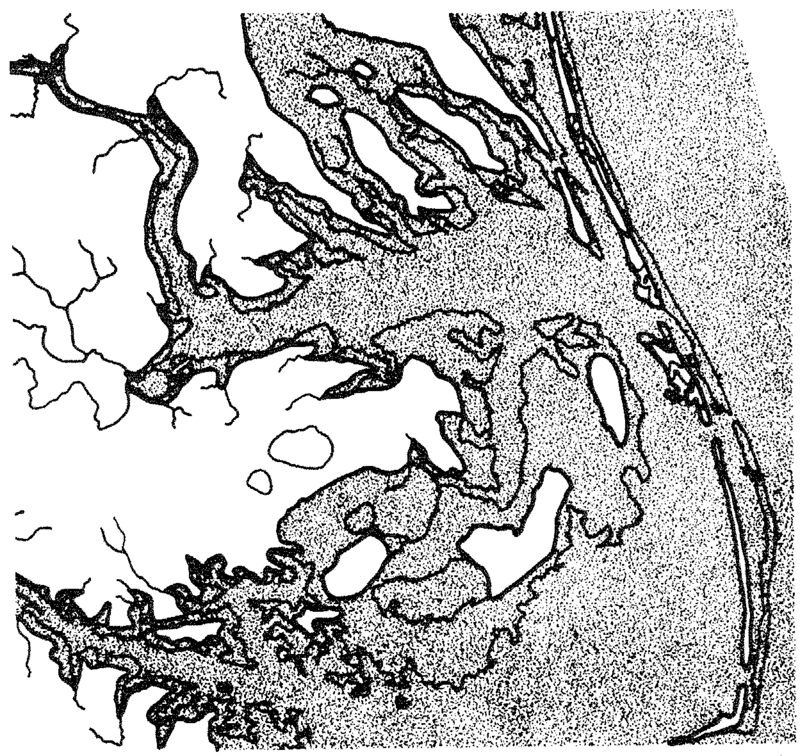
a. 31 January 1972. b. 19 July 1971.

Figure 21. Surface temperatures (°C) in Albemarle Sound during January 1972 and July 1971 (from Bowden and Hobbie 1977).

Because of the continuing rise in sea level, the resulting Albemarle Sound is a complex of broad, shallow aquatic environments that extends many miles into the coastal plain. Because of the low regional slope, the relatively slow rate of flooding produces major and rapid rates of lateral response characterized by extensive shoreline recession. The entire coastal system, including the estuaries, maintains its integrity through time as it migrates upward and landward by a systematic evolutionary succession: the incised drainages are drowned as the estuaries and barrier bar system displace the fluvial system landward. This evolutionary succession is demonstrated in a series of two maps (Figures 22a and 22b). The first shows the reconstructed shoreline position at 10,000 years B.P. Assuming transgression continues at the present rate, the second map projects the position of the Albemarle Sound shoreline 1000 years A.P. (after present or A.D. 3000).



a. 8,000-10,000 years ago.



b. 1,000 years in the future.

Figure 22. Past and future shorelines of Albemarle Sound.

CHAPTER 3

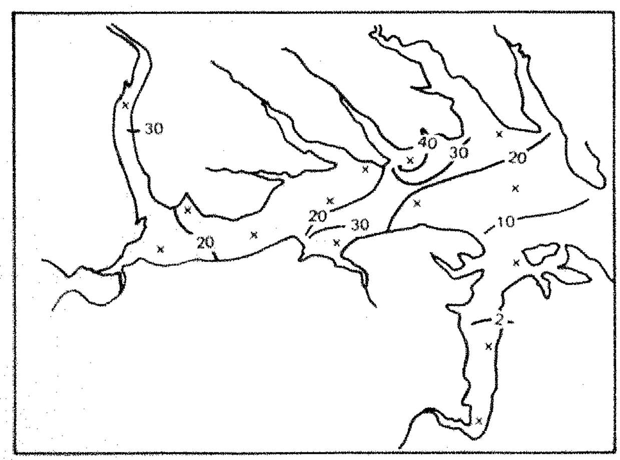
BIOLOGICAL COMPONENTS

3.1 PRIMARY PRODUCERS AND DETRITUS

There have been no reports of direct phytoplankton cell counts in Albemarle Sound. The North Carolina Division of Environmental Management is currently embarked upon a water quality survey of the Sound that includes phytoplankton cell counts (R.E. Holman, Natural Resources and Community Development, Division of Environmental Management, Edenton, North Carolina; pers. comm.). Since Albemarle Sound is typically fresh to oligohaline, it is reasonable to assume that the phytoplankton population is dominated by dinoflagellates, blue-green algae, and diatoms (Copeland et al. 1974a). Indeed, summer blue-green algal blooms in the Chowan River have attracted much attention during the past 10 years (Stanley and Hobbie 1977; Witherspoon et al. 1979).

Typically, the distribution of phytoplankton in Albemarle Sound is patchy and variable (Bowden and Hobbie 1977). The chlorophyll a concentrations reported by Bowden and Hobbie (1977) are here used to characterize phytoplankton seasonality and distribution in Albemarle Sound. Their reported values are corrected for phaeophytin, and thus represent a simple estimate of the viable phytoplanktonic biomass. The numbers should be considered relative because it is well known that the amount of chlorophyll per algal cell will change with changes in nutrient or light conditions.

a. January 1971.



b. April 1972.

Figure 23. Chlorophyll a (μg/l) in Albemarle Sound during January 1971 and April 1972 (from Bowden and Hobbie 1977).

Chlorophyll a concentrations were lowest in the winter and highest in the spring and summer (Figures 23a and 23b). The highest concentrations tended to appear in the tributary-dominated sections of the estuary, although there were some high concentrations in the lower estuarine section.

Bloom conditions have occurred in Albemarle Sound (personal observations); these may be controlled by the flushing rates of the upper reaches of the sound. For example, the high flow conditions after Hurricane Ginger in 1970 apparently washed many of the algae out of the sound, and a bloom did not occur in 1971 (Bowden and Hobbie 1977). By the following year, however, when conditions had stabilized and as temperatures rose in April, extensive blooms occurred throughout the sound (Bowden and Hobbie 1977). There is some evidence that during times of reduced stream inflows (similar to the drought of 1981), saltwater encroachment upstream depresses blue-green algae production (Hans Paerl, Institute of Marine Science, University of North Carolina, Morehead City; pers. comm.).

Typically, submerged grasses play an important role in the primary productivity of an oligohaline estuary (Copeland et al. 1974a). Generally, submerged plants cover only a small percentage of the surface area of the estuary, but contribute a much larger percentage to the total primary productivity.

In the absence of reports on the submerged aquatics in Albemarle Sound, we can make some assumptions about their role there from the studies done by Zenkevitch (1963) on the Baltic Sea, one of the world's best examples of an oligohaline estuarine system. The submerged plants there are generally more prevalent in the lower reaches of the estuary and become infrequent farther up the sound to the tributaries, possibly because of decreased light attenuation upstream.

A seasonal pattern in the abundance and biomass of the submerged aquatic plants can be assumed from information available about the nearby Pamlico River Estuary (Davis and Brinson 1976). There, a summer increase in productivity of submerged plants resulted in the largest biomass during early fall and the smallest biomass during early spring.

Eurasian watermilfoil (*Myriophyllum spicatum*) is present in Albemarle Sound, but has not reached the nuisance growth conditions that have been prevalent in Currituck Sound over the past 20 years (Davis et al. 1977). There is some evidence, however, that watermilfoil is increasing in Albemarle Sound, especially in and around the Alligator River.

The influx of detritus and organic matter from upstream sources is important to an oligohaline estuary such as Albemarle Sound as a basis for the food web (Copeland et al. 1974a). The highest detrital concentrations typically occur at the head of the estuary and in the mouths of the many tributaries entering Albemarle Sound.

Concentrations of suspended matter in the incoming water from the tributaries can be relatively high in Albemarle Sound (Heath 1975; Table 8) compared to those of estuaries with less inflow. A large percentage of the total residue settles out of the water once it reaches quiescent conditions. These materials settle to the bottom and become part of the bacterial recycling and animal reworking that take place in the sediments. The suspended residue (i.e., material that does not settle out of the water for long periods of time) is mainly dissolved organic and inorganic materials, contributing to a relatively high biochemical oxygen demand (5-day BOD).

A large seasonal variability exists in the amount of organic matter entering the estuary. Representative summer and fall concentrations are given in Heath (1975) (Table 8). The highest concentrations normally occur during late summer and fall, corresponding to the die-off of plants in the watershed, streams, and estuary.

With the number of streams entering Albemarle Sound and the substantial freshwater input, Albemarle Sound receives a large loading of detritus and organic carbon each year. It is not possible to delineate the amount of materials coming into the system from different sources (i.e., nonpoint marshes, releases from sediments, point sources, and groundwater). Likewise, data do not exist to

Table 8. Residue and biochemical oxygen demand (BOD) of water entering Albemarle Sound during 1974 in mg/l (from Heath 1975).

Constituent	Alligator River			Scuppernong River	
	June	August	November	August	November
Total residue	240		1,610		762
Organic	138		320		170
Non-organic	102		1,290		592
Suspended residue	47	14	26	49	493
Organic	21	10	22	6	87
Non-organic	26	4	4	43	406
5-day BOD	3.5	1.7	2.3	1.8	1.6

estimate the carbon use by sediment respiration and the amount stored in the sediments during sedimentation.

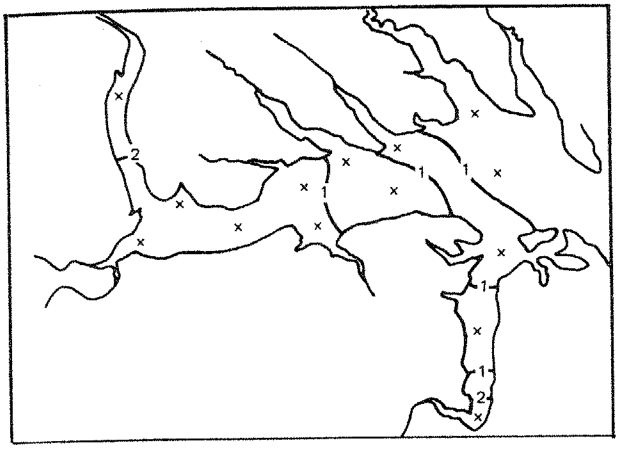
3.2 NUTRIENT DYNAMICS

An extensive survey of the nutrients and their fates was conducted in Albemarle Sound during the 1970's (Bowden and Hobbie 1977). This survey serves as the base for nutrient information. Nitrogen and phosphorus are elements frequently considered limiting to phytoplankton productivity in natural waters, and nitrogen is generally considered to be the most limiting in Atlantic coast estuaries (Kuenzler et al. 1979). Albemarle Sound is suggested to have adequate supplies of both phosphorus and nitrogen for abundant phytoplankton growth (Bowden and Hobbie 1977).

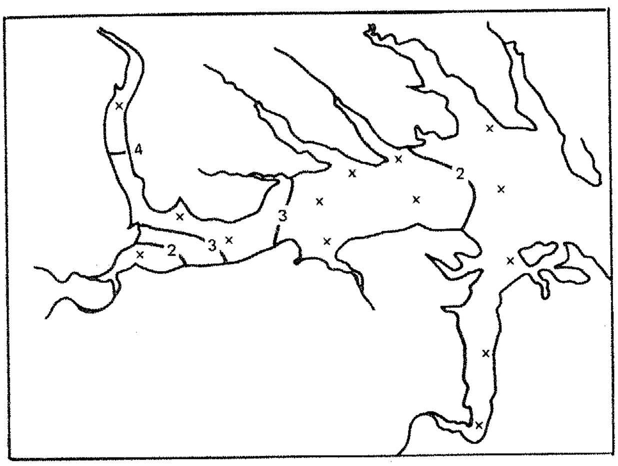
Concentrations of phosphorus in Albemarle Sound Estuary are variable in both time and space (Bowden and Hobbie 1977). In general, because most phosphorus comes from upland sources, the higher concentrations are in the upstream areas and the lower concentrations are in the sound itself. The greatest concentrations of phosphorus in Albemarle Sound occur during winter influxes, whereas lowest concentrations occur during summer (Figures 24a, 24b, and 25). Peaks in phosphorus concentrations in the nearby Pamlico and Neuse Estuaries occur during the summer. Compared to those of other estuaries in North Carolina, the phosphorus concentrations in Albemarle Sound are relatively low (i.e., seldom more than 5 µg-at/l), probably because of the low erosion rates in the Albemarle Sound upland watershed. A diagram of concentrations of total phosphorus in Albemarle Sound indicates that nutrients penetrate far into the sound from the tributaries (Figure 25). For example, the 5 µg-at/l concentration plume penetrated 60 km (37 mi) into Albemarle Sound from the Roanoke River.

There is no proven criterion for the level of phosphorus that is unhealthy for an estuary. Ketchum (1969), however, suggested that most highly eutrophic estuaries on the east coast have total phosphorus concentrations in excess of 2.5 µg-at/l. Although total phosphorus is less abundant in Albemarle Sound than in the other North Carolina estuaries, this threshold is still exceeded on numerous occasions throughout the estuary. Thus, one may conclude that phosphorus in Albemarle Sound is high enough to create eutrophic conditions when other factors are not limiting.

In general, the concentration of nitrogen compounds in Albemarle Sound is high in the winter and low in the summer (Bowden and Hobbie 1977). Similar to the situation found in the Pamlico River



a. September 1971.



b. January 1972.

Figure 24. Total inorganic phosphorus (μg-at/l) in Albemarle Sound during September 1971 and January 1972 (from Bowden and Hobbie 1977).

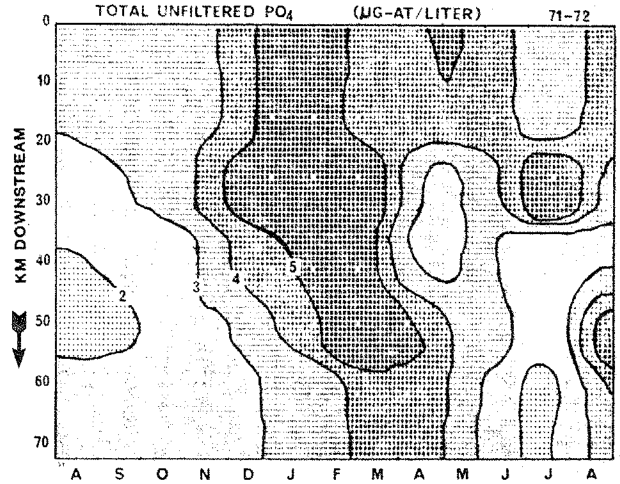


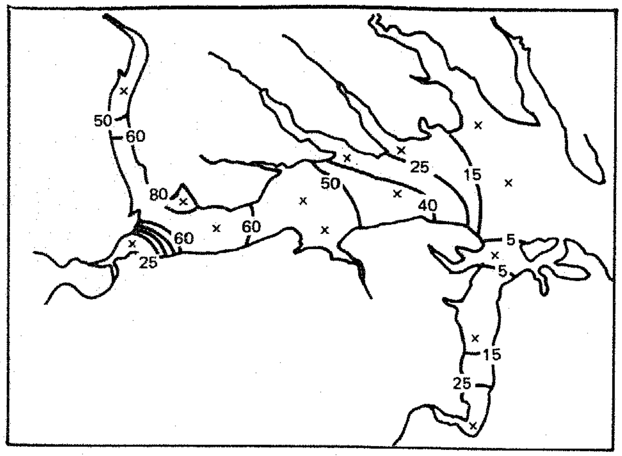
Figure 25. Annual pattern of total inorganic phosphorus (μg-at/l) in Albemarle Sound during 1971-72 (from Bowden and Hobbie 1977).

Estuary to the south, most nitrogen inputs occur in the winter while most nitrogen assimilation by phytoplankton occurs in the summer (Kuenzler et al. 1979).

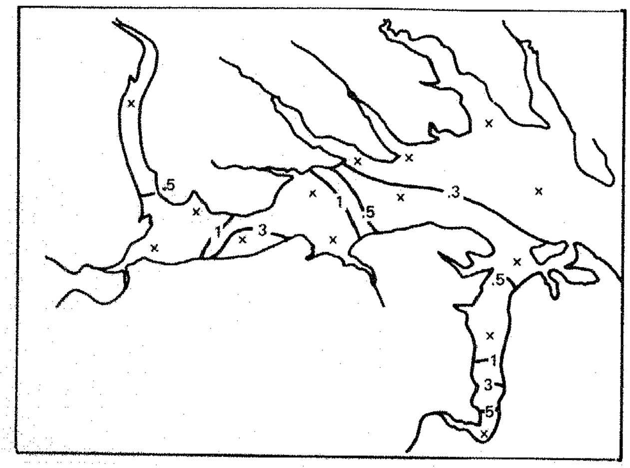
Nitrogen is present in the water in several forms. The most abundant inorganic form is nitrate, but there are significant concentrations of ammonia and nitrite. Organic nitrogen exists in both dissolved and particulate forms. Nitrate concentrations range between a trace and 80 μg-at NO_3-N/l (i.e., about 5 mg NO_3/l). Although a normal high concentration is about half the latter value, the peak values of nitrate nitrogen indicate that Albemarle Sound has enough nutrient input to support large algal blooms. The high concentrations of nitrate present in Albemarle Sound during the winter (Figure 26a) could generally be traced to inputs from tributaries around the sound. Normally, the summer concentrations of nitrate were relatively low (Figure 26b), but in some years there was a strong increase by October (Bowden and Hobbie 1977). The inflow of nitrate penetrated far into the estuary during the winter and early spring (Figure 27).

This pattern is substantially similar to that of the lower Chowan River at its juncture with Albemarle Sound (Stanley and Hobbie 1977). A distinct nitrate maximum exists there during the winter and a minimum during the summer, as a result of high winter runoff and high summer algal nitrate uptake. The pattern is also similar to situations observed in the Pamlico River Estuary (Hobbie 1974; Kuenzler et al. 1979) and the Neuse River Estuary (Hobbie and Smith 1975).

Ammonia is also important to algal productivity; its uptake is probably three times the nitrate uptake in dense algal populations (E.J. Kuenzler, University of North Carolina, Chapel Hill; pers. comm.). Ammonia concentrations in Albemarle Sound have been found to be variable both spatially and temporally. Again, in general, the highest concentrations are found



a. February 1971.



b. September 1971.

Figure 26. Nitrate nitrogen (μg-at/l) in Albemarle Sound during February and September 1971 (from Bowden and Hobbie 1977).

during the winter and the lowest during the summer (Figure 28). There are some secondary increases, however, during fall and early summer periods corresponding to some temporary periods of high runoff. In general, ammonia nitrogen is more abundant in the mouths of the tributaries than it is in the sound itself, which is evidence that the tributaries are a source of ammonia.

In general, ammonia nitrogen is less abundant than nitrate nitrogen, although the peak concentrations range as high as 50 μg-at NH_4-N/l (i.e., about 1 mg NH_4/l). As with nitrate, ammonia concentrations were similar in the upper reaches of Albemarle Sound and in the Chowan River

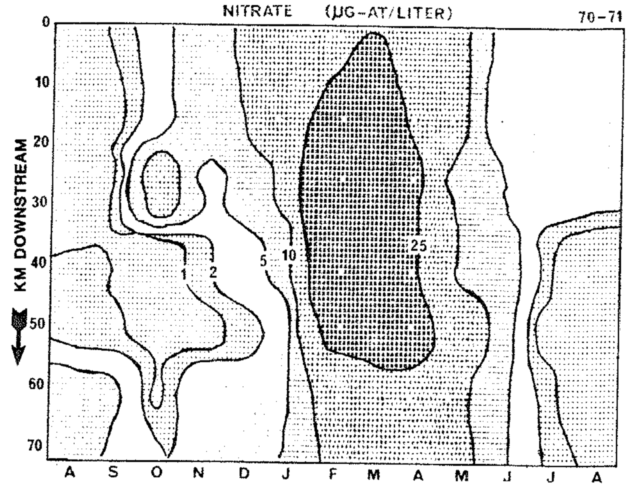


Figure 27. Annual patterns of nitrate nitrogen (μg-at/l) in Albemarle Sound during 1970-71 (from Bowden and Hobbie 1977).

(Stanley and Hobbie 1977). Seasonal and spatial concentration patterns were similar to the Neuse River Estuary (Hobbie and Smith 1975) and the Pamlico River Estuary (Hobbie 1974).

Dissolved organic nitrogen may represent a large portion of the total nitrogen pool in natural systems (Tusneem and Patrick 1971; Harrison and Hobbie 1974; Kuenzler et al. 1979) and may be

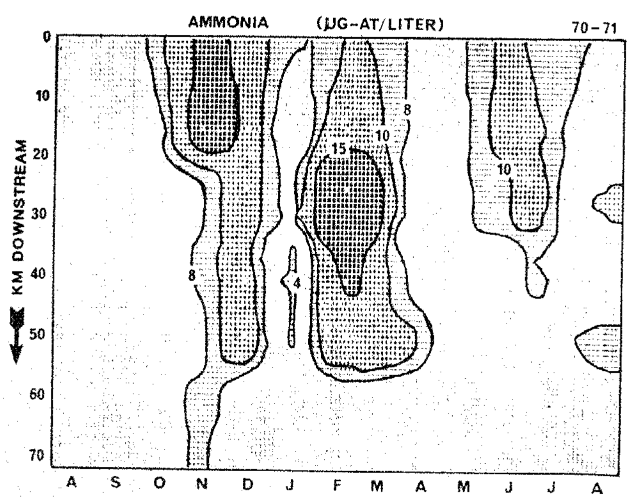


Figure 28. Annual pattern of ammonia nitrogen (μg-at/l) in Albemarle Sound during 1970-71 (from Bowden and Hobbie 1977).

about 90% of the total nitrogen present in estuarine waters (Stanley and Hobbie 1977). There is no reason to believe that Albemarle Sound does not follow this same pattern.

3.3 MICROBIAL COMPONENT

A major microbiological problem commonly referred to as the red sore disease affects the fisheries of Albemarle Sound (Esch and Hazen 1980). The implicated microbe for red sore disease is *Aeromonas hydrophila*, a gram negative bacterium found in fresh to brackish water (Hazen 1979). The presence of *A. hydrophila* seems to be associated with high concentrations of decaying organic residue (Esch and Hazen 1980). The occurrence of red sore disease in Albemarle Sound may be associated with the input of high concentrations of organic materials from some of the tributaries (see Section 3.1). The threshold level at which *A. hydrophila* becomes a problem is thought to be 40 colony-forming units (cfu) per milliliter (Esch and Hazen 1980). This concentration is exceeded during the winter and spring (Figure 29) at several locations in Albemarle Sound.

Another microbial problem in the sound is coliform bacteria. The North Carolina Department of Human Resources conducts a shellfish sanitation program at least every 2 years to evaluate the water quality as it relates to the growth of shellfish. If the monitoring stations have a median reading of 70 or more total coliform bacteria, or if 10% of the monitoring stations measure 330 or more coliforms per 100 ml, the area is closed to commercial shellfishing by the North Carolina Shellfish Sanitation Division. Of the 243,000 ha (600,000 acres) of water in Albemarle Sound, about 49,000 ha (121,000 acres) were closed to shellfishing in 1981. About 36,000 ha (89,000 acres) of the 49,000 ha of closed water had little commercial value because only freshwater clams were found in these waters. Most of the closed acreage was near the mouths of the tributaries and the upper portion of Albemarle Sound.

Much of Albemarle Sound is classified as either B or SB by the North Carolina

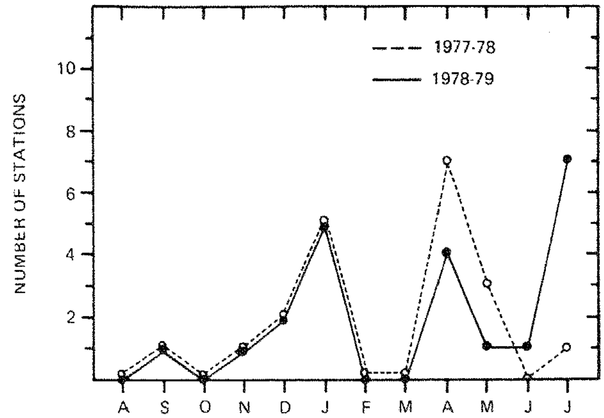


Figure 29. Number of stations (of 20) where the density of *Aeromonas hydrophila* exceeded the 40 cfu/ml threshold level (from Esch and Hazen 1980).

Division of Environmental Management. These classifications mean that the bacterial content of the water makes it unsuitable for human consumption (B) or for commercial shellfishing (SB). These conditions have existed for more than a decade and are thought to be due to septic wastes.

3.4 SECONDARY PRODUCERS

Although zooplankton are an important trophic link in the estuarine food web, no studies have been conducted in Albemarle Sound that include investigations of the zooplankton population and its distribution. A few studies, however, have been conducted in estuaries similar to Albemarle Sound (Zenkevich 1963; Painter 1966a; Stone et al. 1980). Total zooplankton abundance in the oligohaline stretches of the Sacramento-San Joaquin Estuary, California, was small when compared to more saline downstream reaches (Painter 1966a). The main concentration of zooplankton generally occurred in salinities greater than 5 ppt. The zooplankton was dominated by several species of copepods, including *Cyclops*, *Diaptomus*, and *Eurytemora*. Likewise, macrozooplankton (those caught in a 374-μm net) populations in Lake Ponchartrain, Louisiana, were dominated by the copepod *Acartia tonsa* and copepod nauplii (Stone et al. 1980). Cladocerans and crab zoea were other important components of the zooplankton assemblage. February population peaks of A. tonsa (about 1700/m^3) were two orders of magnitude smaller than those typically found in mesohaline areas (reviewed in Bellis 1974). Macrozooplankton abundance peaked in February and was lowest in November. Microzooplankton (those caught in a 79-μm net) in Lake Pontchartrain were dominated by copepod nauplii, adult copepods, and rotifers. The smaller zooplankton were a more diverse group taxonomically than the macrozooplankton and contained many freshwater species.

Using these studies as a rough guide, we assume zooplankton populations would tend to be lower in Albemarle Sound than in the large mesohaline estuaries to the north and south of it in Virginia and North Carolina. We also assume a species composition dominated by fresh- to brackish-water copepods, with numerical abundance and biomass peaking in the spring in response to increased phytoplankton and detrital food (Section 5.3).

No detailed studies have been made of the benthic populations in Albemarle Sound. Wright (1972) surveyed the benthic populations in Croatan Sound, the main connection between Albemarle Sound and Pamlico Sound (Table 9). The benthic fauna is apparently dominated by two polychaete worms (Capitella capitella and Nereis succinea) and two mollusks, principally Rangia cuneata and Macoma balthica. These same benthic organisms, with the exception of Capitella dominate other oligohaline estuaries (Copeland et al. 1974a).

In general, the benthos of these estuaries is characterized by large populations of relatively few species and by overall low biomass, perhaps as a result of rigorous fluctuating environmental conditions. This pattern is assumed to hold for the sound.

Throughout a large portion of Albemarle Sound, there are dense populations of the freshwater clam Rangia cuneata (North Carolina Shellfish Sanitation Division, Raleigh; pers. comm.). These animals have been harvested from time to time and marketed for the production of clam

Table 9. Species distribution by station of benthos in Croatan Sound (from Wright 1972).

Species	% of Station
Polychaeta	
Capitella capitella	63.0
Glycera dibranchiata	2.1
Nereis succinea	52.5
Scolecolepides viridis	2.1
Isopoda	
Chirodotea nigrescene	8.4
Cyathura polita	27.3
Amphipoda	
Unknown amphipod	16.8
Corophium sp.	12.6
Gammarus sp.	8.4
Decapoda	
Pinnotheres ostreum	8.4
Mollusca	
Brachiodontes recurvus	10.5
Crassostrea virginica	10.5
Macoma balthica	50.4
Rangia cuneata	12.6
Platyhelminthes	
Unknown turbellarian	8.4

chowder (Chestnut and Davis 1975). In recent years, however, these clams have been shown to be heavily contaminated with a bacterial mixture that does not appear to be pathogenic (Comar 1981).

The diversity of nekton populations in Albemarle Sound is relatively low compared to the estuaries farther south (Hester and Copeland 1975; Hassler et al. 1981). Of the 29 species collected in Albemarle Sound from 1972 through 1973 (Table 10), the bay anchovy, Atlantic croaker, white perch, blueback herring, hogchoker, white catfish, blue crab, and spot accounted for 94% of the trawl catch and 85% of the biomass (Hester and Copeland 1975). Hassler et al. (1981) found that young-of-the-year striped bass were also prominent in western Albemarle Sound.

Table 10. Species trawled in Albemarle Sound, 1972-73 (from Hester and Copeland 1975).

Scientific name	Common name	Number	% of total number	Biomass (g)	% of total biomass[a]
Anchoa mitchilli	Bay anchovy	2,094	23.8	1,014.4	0.7
Micropogonias undulatus	Atlantic croaker	1,890	21.5	6,821.1	4.7
Morone americana	White perch	1,320	15.8	54,134.0	37.2
Alosa aestivalis	Blueback herring	726	8.2	248.6	0.2
Trinectes maculatus	Hogchoker	610	6.9	10,565.7	7.3
Ictalurus catus	White catfish	612	6.9	26,191.1	18.7
Callinectes sapidus	Blue crab	610	6.9	20,008.3	13.8
Leiostomus xanthurus	Spot	419	4.8	3,456.4	2.4
Anguilla rostrata	American eel	156	1.8	7,135.7	4.9
Brevoortia tyrannus	Atlantic menhaden	142	1.6	278.6	0.2
Alosa pseudoharengus	Alewife	57	--	--	--
Paralichthys lethostigma	Southern flounder	49	--	--	--
Dorosoma cepedianum	Gizzard shad	21	--	--	--
Ictalurus punctatus	Channel catfish	16	--	3,863.5	2.7
Etheostoma olmstedi	Tessellated darter	16	--	--	--
Ictalurus nebulosus	Brown bullhead	13	--	1,552.3	1.1
Perca flavescens	Yellow perch	13	--	--	--
Lepomis gibbosus	Pumpkinseed	8	--	--	--
Opisthonema oglinum	Atlantic thread herring	3	--	--	--
Penaeus aztecus	Brown shrimp	4	--	--	--
Rithropanopeus harrissi	Mud crab	4	--	--	--
Cynoscion regalis	Weakfish	2	--	--	--
Palaemonetes pugio	Grass shrimp	2	--	--	--
Bairdiella chrysura	Silver perch	1	--	--	--
Amia calva	Bowfin	1	--	--	--
Symphurus plagiusa	Blackcheek tonguefish	1	--	--	--
Notropis sp.	Freshwater minnow	1	--	--	--
Paralichthys dentatus	Summer flounder	1	--	--	--
Lepisosteus osseus	Longnose gar	1	--	--	--

[a]Based on total biomass of all species.

The nekton catch in Albemarle Sound varied considerably from 1955 to 1980 (Table 11). Catch per unit effort data in Albemarle Sound indicate that orders of magnitude differences in population densities occur from one year to another (Hassler et al. 1981). Populations of bay anchovies, blueback herring, croaker, and spot fluctuate more from year to year than populations of hogchoker, striped bass, and blue crab.

Large seasonal fluctuations are evident for the Albemarle Sound nekton (Figure 30). The highest peak in the numbers of nekton in the catch is during the spring months of April through June and a secondary peak occurs in late summer/early fall. The biomass peaks during the winter and again during the mid-summer season (see Section 3.5). Biomass is greater in the western sound, (Figure 31) reflecting the preponderance of anadromous and indigenous fish there.

Table 11. Mean catch per trawl in western Albemarle Sound, 1955-80 (from Hassler et al. 1981).

Species	1955	1956	1957	1958	1959	1960	1961	1962	1963
Blueback herring	0.2	49.3	273.2	98.9	89.3	15.0	27.3	126.3	11.5
Bay anchovy	41.5	2.2	395.0	4.3	0.5	41.6	0.6	0.1	1.7
White perch	1.8	3.5	31.4	33.2	20.4	11.9	45.9	23.4	20.6
Striped bass	3.3	19.1	5.7	0.2	23.9	5.9	10.3	7.9	4.8
Atlantic croaker	5.1	6.8	35.9	10.2	1.9	5.9	2.3	0.2	0.9
Spot	2.3	13.2	37.9	0.2	8.1	36.3	5.8	1.4	21.7
Hogchoker	0.7	1.0	3.2	1.7	2.8	3.9	3.9	1.5	3.2
Blue crab	--	--	--	--	0.8	3.1	2.0	0.3	1.7

Species	1964	1965	1966	1967	1968	1969	1970	1971
Blueback herring	6.8	23.5	6.0	0.2	13.7	1.1	9.8	19.7
Bay anchovy	6.9	1.2	1.0	17.9	4.7	2.6	0.1	11.6
White perch	27.8	22.7	10.5	28.5	26.8	26.4	38.4	54.4
Striped bass	3.1	10.1	3.4	23.4	6.6	2.9	12.5	2.9
Atlantic croaker	6.8	1.2	0.7	32.5	6.1	0.5	0.1	22.8
Spot	34.9	4.5	2.9	45.7	6.3	6.3	10.4	41.7
Hogchoker	2.2	2.2	0.9	4.2	3.4	0.7	1.9	4.1
Blue crab	1.8	0.9	1.3	16.6	10.3	9.5	6.2	10.8

Species	1972	1973	1974	1975	1976	1977	1978	1979	1980
Blueback herring	10.8	37.9	7.1	37.3	11.4	11.8	43.0	2.0	16.0
Bay anchovy	5.0	2.7	3.8	13.3	5.5	6.0	3.2	1.0	3.6
White perch	50.5	32.5	53.2	88.2	59.5	66.0	239.6	175.7	75.5
Striped bass	2.5	2.0	5.5	10.8	10.5	3.6	0.6	0.6	0.5
Atlantic croaker	19.4	3.6	5.9	11.0	51.8	11.5	1.3	1.7	0.2
Spot	9.1	0.5	6.2	20.6	112.9	78.5	0.7	4.9	0.8
Hogchoker	6.1	6.0	1.3	1.7	5.1	4.1	2.2	5.9	--
Blue crab	4.3	2.1	1.3	7.2	13.4	9.0	0.5	1.5	--

Three nekton populations characterize the sound, accounting for the qualitative differences illustrated by the catch data (Hester and Copeland 1975). The indigenous fish fauna occupying the extreme western sound area is dominated by white perch, catfish, and gizzard shad and makes up the large winter peak in biomass. A migratory population inhabits the eastern portion of the sound on a seasonal basis. This population is dominated by spot, Atlantic croaker, anchovies, and blue crabs and makes up most of the spring and summer population. The third group is the anadromous population, composed primarily of blueback herring and striped bass, which migrate into the freshwater streams to spawn in early spring. The juveniles move down into the estuary in early summer.

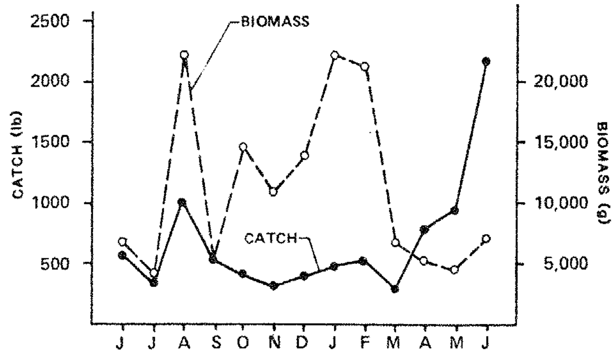


Figure 30. Catch and biomass of nekton in Albemarle Sound, 1972-73 (from Hester and Copeland 1975).

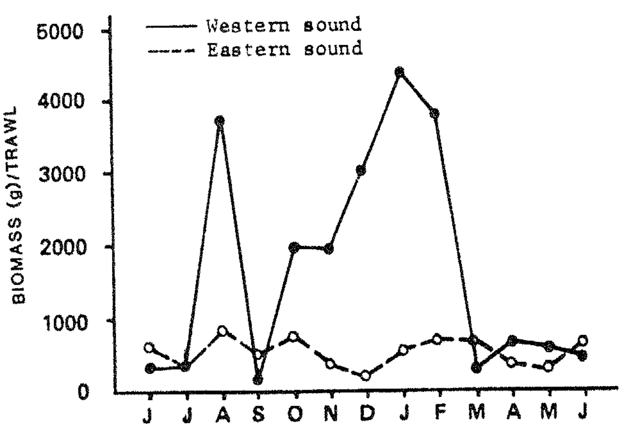


Figure 31. Nekton biomass per trawl in Albemarle Sound, 1972-73 (from Hester and Copeland 1975).

Waterfowl are an important though little studied part of the Albemarle Sound ecosystem. The Albemarle Sound estuary is used by at least 17 species of overwintering waterfowl (Table 12). Average populations presented in Table 12 are based on yearly midwinter waterfowl surveys and represent relative abundances at a single point in the overwintering season. Wood ducks (Aix sponsa) are also found in the estuary, but are concentrated in the river floodplains. Waterfowl use is largely restricted to the river tributaries rather than the open sound (Don Harke, USFWS, Wildlife Assistance, Raleigh, North Carolina; pers. comm.). An average 3.6% (range 5,700-30,800 birds) of the overwintering migratory waterfowl in Carolina was surveyed in the estuary during the 1978-82 midwinter censuses. In contrast, waterfowl populations averaged over five times greater (range 64,700-131,300 birds) in nearby Currituck Sound. This small estuary supported an average 20.5% of the State midwinter count of birds during the 5-year period.

Table 12. Migratory waterfowl species present in Albemarle Sound, ranked in approximate order of abundance (based on USFWS unpublished data, Midwinter Waterfowl Surveys, 1978-1982).

Common name	Scientific name
Canada goose	Branta canadensis
Snow goose	Chen caerulescens
Whistling swan	Cygnus columbianus
Ringed-neck duck	Aythya collaris
American coot	Fulica americana
Mallard	Anas platyrhychos
Black duck	Anas rubripes
Scaup	Aythya affinis, A. marila
American wigeon	Anas americana
Green winged teal	Anas crecca
Gadwall	Anas strepera
Redhead	Aythya americana
Ruddy duck	Oxyura jamaicensis
Bufflehead	Bucephala albeola
Canvasback	Aythya valisineria
Northern pintail	Anas acuta
Merganser	Mergus spp., Lophodytes cucullatus

3.5 LIFE HISTORY STRATEGIES

The nekton of Albemarle Sound includes anadromous, catadromous, migratory, and indigenous species, each group having a distinctive life history strategy. Dominating the anadromous fish population of Albemarle Sound are the blueback herring (Alosa aestivalis), the alewife (A. pseudoharengus), and the striped bass (Morone saxatilis). Of lesser importance are the American shad (A. sapidissima), the hickory shad (A. mediocris), and the Atlantic sturgeon (Acipenser oxyrhynchus). The Atlantic sturgeon, once fished commercially, is now rarely taken in the Albemarle Sound area. Anadromous fish spend a large portion of their life at sea and ascend into coastal rivers to spawn (Talbot and Sykes 1958; Walburg and Nichols 1967). Spawning normally occurs after a spring (April-May) run upstream from the ocean by the ripe adults, and the young remain in the stream until late spring or early summer when they move downstream into the estuary (Trent and Hassler 1968). The juveniles remain in the estuary until fall when they move out into the ocean where they may migrate south during the winter. Here they remain until they reach maturity (Figure 32).

A moderate river flow rate is required for the spawning success of many of the anadromous species, especially striped bass (Hassler et al. 1981). High river discharge is detrimental when the eggs and larvae are carried into river swamps where their survival is low. If the river flow rate is too high after hatching, the larvae may also be carried downstream, out of the river system beyond the general nursery area. Low river flow is detrimental because the eggs need to be moving to complete their hatching cycle.

The life cycle of the striped bass is perhaps the best studied of any fish in the sound. Sexually mature striped bass begin to migrate upstream from the sound in late March and continue through early May (Trent and Hassler 1968). Males migrate to the spawning area first, and females follow around the end of April. They spawn when water temperature is around 18°C (64°F). Each female may release from 14,000 (3-lb fish) to 5 million (50-lb fish) eggs. The eggs hatch in about 2 days and the young drift downstream to the calmer waters of western Albemarle Sound. After spawning, the adult fish return to the sound.

The young fish remain in the nursery area throughout most of their first growing season, reaching a length of 75 to 150 mm (3 to 6 inches). Recent studies in the Potomac Estuary (Boynton et al. 1982) indicate that the year-class strength of striped bass is most likely determined before the end of their first growing season. Slow growth of some year classes of striped bass during their first year of life in Albemarle Sound may be compensated for by increased growth during their second and third growing seasons (Nicholson 1964).

Although certain segments of the Atlantic coast stocks leave their native areas and make coastal migrations, the Albemarle Sound striped bass generally do not make coastal migrations. During winter Albemarle Sound striped bass congregate in deep pools near the river mouths and in the sound.

Catadromous species spend most of their life in the freshwaters of streams. Adults make their way down the streams, through the estuary, and out to the ocean for spawning. After hatching, the larvae make their way from the ocean back to freshwater streams. The estuary serves as an interim nursery area for the larvae of catadromous species.

The American eel (Anguilla rostrata) is the only catadromous fish in Albemarle Sound. It supports an important commercial fishery during the adult influx into the sound from the tributary streams.

Dominating the catch in the eastern part of Albemarle Sound are three migratory species (Hester and Copeland 1975): Atlantic croaker (Micropogonias undulatus), spot (Leiostomus xanthurus), and the blue crab (Callinectes sapidus). Of lesser importance are the grey trout (Cynoscion regalis), menhaden (Brevoortia tyrannus), southern flounder (Paralichthys lethostigma), and grooved shrimp (Penaeus sp.). Other species occasionally enter as migratory fish and in the forage fish populations of eastern Albemarle Sound. In years of drought, when salinities increase, a more marine assemblage (e.g., bluefish and ray) will migrate into the sound.

The life history of the migratory species (Figure 32) begins with spawning at sea (except the grey trout, which probably spawns in salty sounds). After hatching, the larvae make their way through inlets in the barrier islands up into the estuary where they selectively occupy shallow, productive nursery areas. This migration generally occurs during the early spring, and the young remain in the estuarine nursery zone through most of the summer. The the estuary provides abundant foodstuffs for the larvae to develop

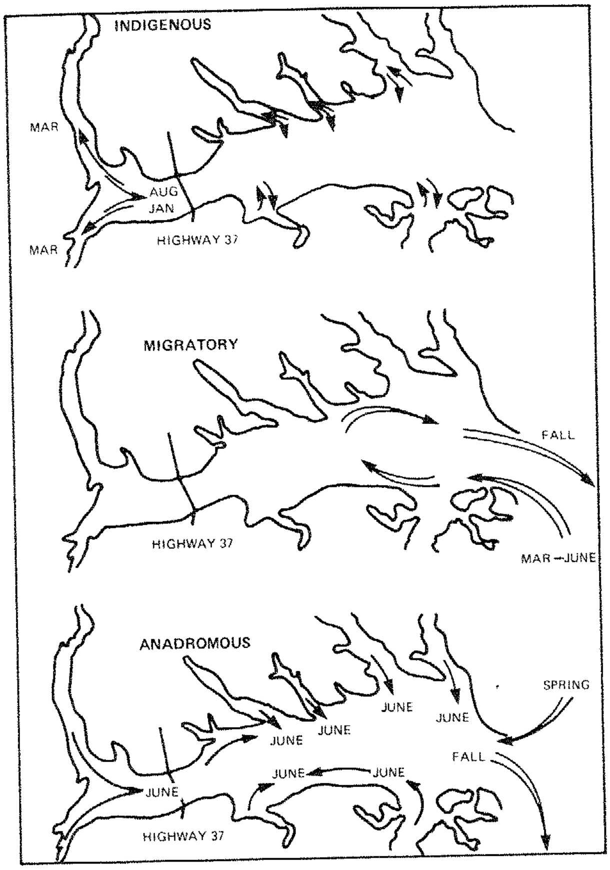


Figure 32. Diagram of anadromous fish movement in Albemarle Sound (from Hester and Copeland 1975).

through the juvenile stage. Young-of-the-year fish migrate back to the ocean to complete their life cycle.

Several species are indigenous to Albemarle Sound and occupy the estuary year-round. Their movements (Figure 32) are restricted to short distances in and out of the tributary streams and back and forth in the sound itself.

The most prominent indigenous species is the bay anchovy (*Anchoa mitchilli*). Another abundant species is the grass shrimp (*Palaemonetes pugio*). The indigenous species constitute a significant portion of the forage fish for migratory and anadromous species that are so important to the commercial fishery of Albemarle Sound.

Several indigenous species are commercially harvested in Albemarle Sound (Hester and Copeland 1975; Hassler et al. 1981), including white catfish, (*Ictalurus catus*), channel catfish (*Ictalurus punctatus*), white perch (*Morone americana*), and yellow perch (*Perca flavescens*), and the catches are large in most years (see Section 5.1). These species primarily use the western half of Albemarle Sound and move to and from the mouths of the rivers on a seasonal basis in response to freshwater inflows.

CHAPTER 4

ECOLOGICAL INTERRELATIONSHIPS

4.1 TROPHIC STRUCTURE

Food chains in brackish water estuaries (oligohaline systems) are typically abbreviated (Copeland et al. 1974a). Most of the fishes are plankton or zoobenthos consumers and as such form the highest trophic level of the abbreviated food chain. Few specific studies of the trophic structure and food chain partitioning have been conducted for Albemarle Sound; however, food habits for yearling and adult striped bass have been studied (Trent and Hassler 1966; Manooch 1973).

Some clues concerning the trophic structure of Albemarle Sound may be deduced from studies of similar oligohaline estuaries (Darnell 1961; Zenkevitch 1963; Levine 1980). Because of the dominance of tributary inputs, the lowest trophic level of the oligohaline system is typically incoming organic detritus from the watershed (Fairbanks 1963). Detritus forms a large portion of the diet of the benthos and the meiobenthos, and these detritivores are in turn fed upon by fish. Estuarine fish are characterized as omnivorous and opportunistic feeders. Food categories and the trophic spectrum for important members of the Albemarle Sound brackish water community are illustrated in Figure 33. Most food chains are no more than three trophic levels in length (Darnell 1961).

Many fish species using estuaries like Albemarle Sound shift their food preferences as they grow (Darnell 1961; Trent and Hassler 1966; Levine 1980). The Atlantic croaker, for example, shifts from a predominantly zooplankton diet during the young nursery ground stages, to a more diversified diet of benthos at the juvenile stage, and to fish and benthos as adults (Figure 34). The same kinds of shifts occur with the anadromous fish using Albemarle Sound. The river herring, for example, feed primarily on zooplankton during their larval and juvenile stages in the upper estuary and switch to a fish diet as they grow older and move out to the ocean for winter (Hildebrand and Schroeder 1972).

As with river herring, young striped bass (less than 100 mm or 4 inches) from Albemarle Sound consume few fish. No studies of small striped bass have been conducted in Albemarle Sound, but in the oligohaline portions of the Potomac Estuary striped bass less than 100 mm (4 inches) eat mostly insects and polychaetes (Boynton et al. 1981). Albemarle Sound striped bass probably shift to a fish diet when about 100 mm in length. Manooch (1973) found that 97% of the food volume in striped bass over 125 mm (5 inches) consisted of fish. Clupeids, including river herring and gizzard shad, were the predominant species eaten. River herring were the only species eaten by adult striped bass during the spring herring migrations.

4.2 NURSERY AREAS

Nursery areas in estuaries are typically nearshore shallow areas (Figure 35) that support large populations of post larval and juvenile fishes and crustaceans during their first growing season (Street et al. 1975). The density of the young of many species is relatively high in the nursery ground areas. Nursery utilization

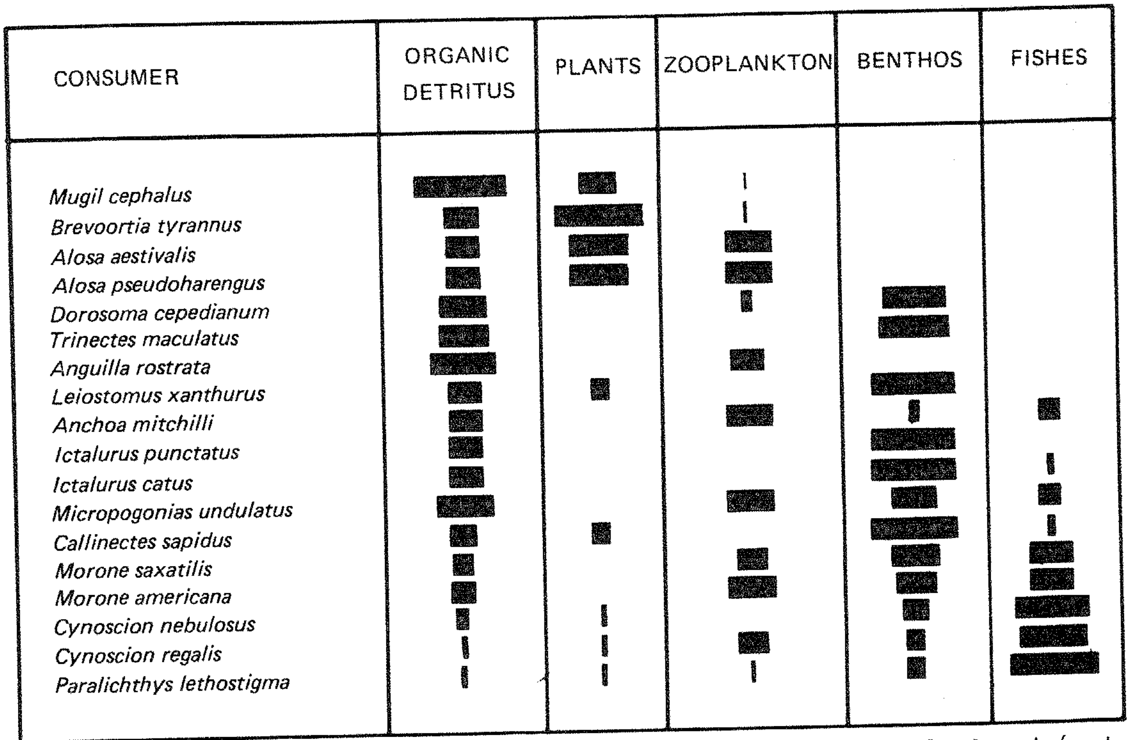


Figure 33. Trophic spectrum for important consumers in Albemarle Sound (modified from Darnell 1961).

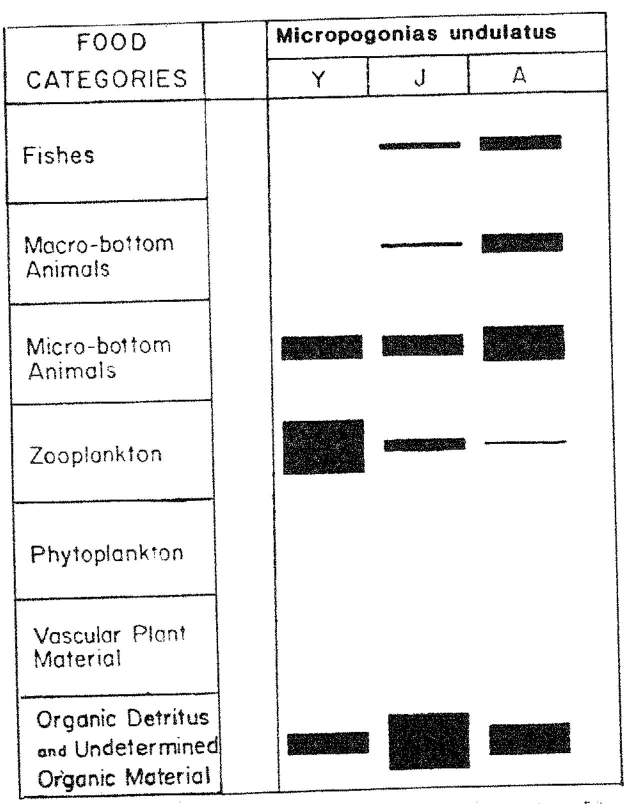


Figure 34. Trophic spectrum for the Atlantic croaker, Micropogonias undulatus (from Darnell 1961).

is considered to be one of the more important functions of estuaries, which provide the basis for many of the recreational and commercial fisheries of this country (McHugh 1966). Spawning generally occurs outside the estuary, and the young juveniles move into the estuarine nursery grounds after going through a larval stage elsewhere. In Albemarle Sound, the majority of the nursery users are juveniles of anadromous species. The adults of these species have normally gone upstream into tributaries to spawn, and the developing juveniles use the brackish water portions of the estuary as nursery grounds. A few migratory species (e.g., blue crab, spot, and Atlantic croaker) use the eastern portion of Albemarle Sound as a nursery area (Hester and Copeland 1975; Street et al. 1975). The extent of that nursery area depends upon the salinity of the lower end of Albemarle Sound, which in turn depends upon the amount of freshwater flowing into the system from the drainage basin.

The western portion of Albemarle Sound is the primary nursery area for juvenile striped bass, with the remainder of the sound used only occasionally (Street

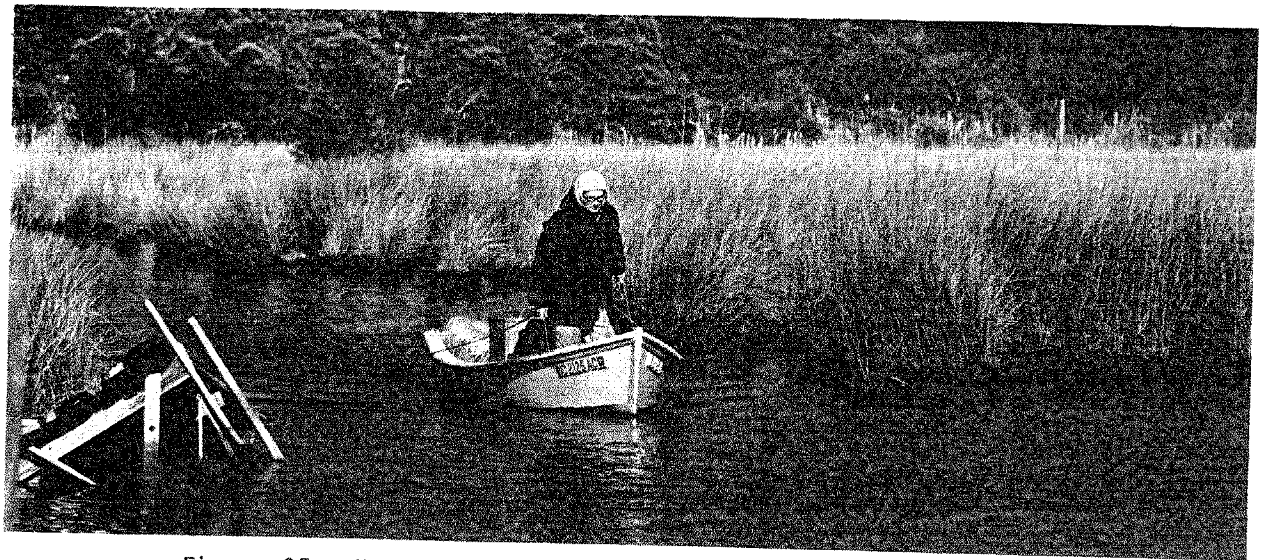


Figure 35. Nearshore nursery area (photo by J. Foster Scott).

et al. 1975; Hassler et al. 1981). The most heavily used nursery areas at the western end of Albemarle Sound are at the mouths of the Chowan and Roanoke Rivers (Figure 36a). Other heavily used nursery areas of the western sound are the northern and southern shores of the western third of the sound. Other important nursery areas for striped bass are the Alligator River and, to some extent, the Pasquotank River. Occasionally, the lower North River is also used as a nursery area by the striped bass.

Nursery areas for the alewife generally coincide with those for the blueback herring in Albemarle Sound (Street et al. 1975; Johnston et al. 1977). Although the largest nursery areas are in the western sound, there are nursery areas throughout the shallow waters and tributaries of most of the sound (Figure 36b). Both species use floodplains of tributaries during the spring for spawning (Pate 1972).

Little work has been done in Albemarle Sound concerning nursery use by migratory fish, but we do know they use the shallow areas of the Alligator River and the more saline areas of the eastern sound (Hester and Copeland 1975). Spot, Atlantic croaker, and blue crabs use the shallow water of Albemarle Sound inside the Outer Banks for nursery areas (Street et al. 1975).

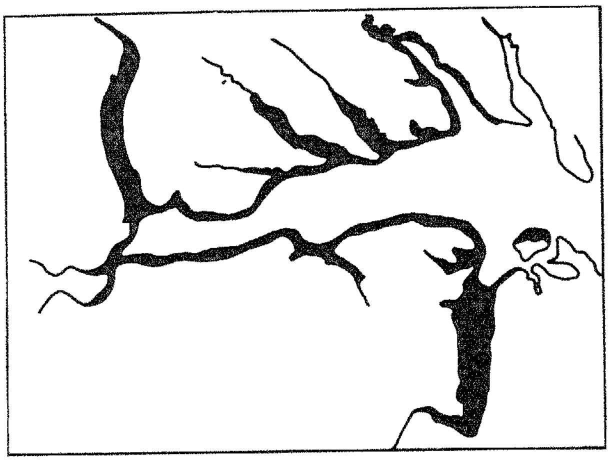
4.3 SPATIAL-TEMPORAL RELATIONSHIPS

Seasons in Albemarle Sound are defined by a combination of tributary inflows and water temperature. The colder months are the times of the highest tributary inflows. Consequently, during the late winter and early spring when freshwater runoff peaks, the sound receives nutrients, detritus, and other materials from upland drainage that collectively drive the system. As the water begins to warm in the spring and solar radiation increases, the phytoplankton productivity increases. This increase in primary productivity is quickly followed by an increase in zooplankton, which support large populations of anadromous and indigenous fishes.

Adult anadromous fishes using Albemarle Sound make a spawning run up the rivers during early spring (Street et al. 1975). Growing juveniles make their way down the tributaries and out into the western portion of the sound. Therefore, juvenile abundance peaks in the sound during the summer (Figure 37). Basically, the timing of migrations of organisms from and into the sound system corresponds to the time of maximum production within the sound.

One characteristic adaptation of organisms to the seasonality existing in temperate estuarine systems is that of

a. Striped bass.



b. Blueback herring and alewife.

Figure 36. Nursery areas of anadromous fish species in Albemarle Sound (from Street et al. 1975).

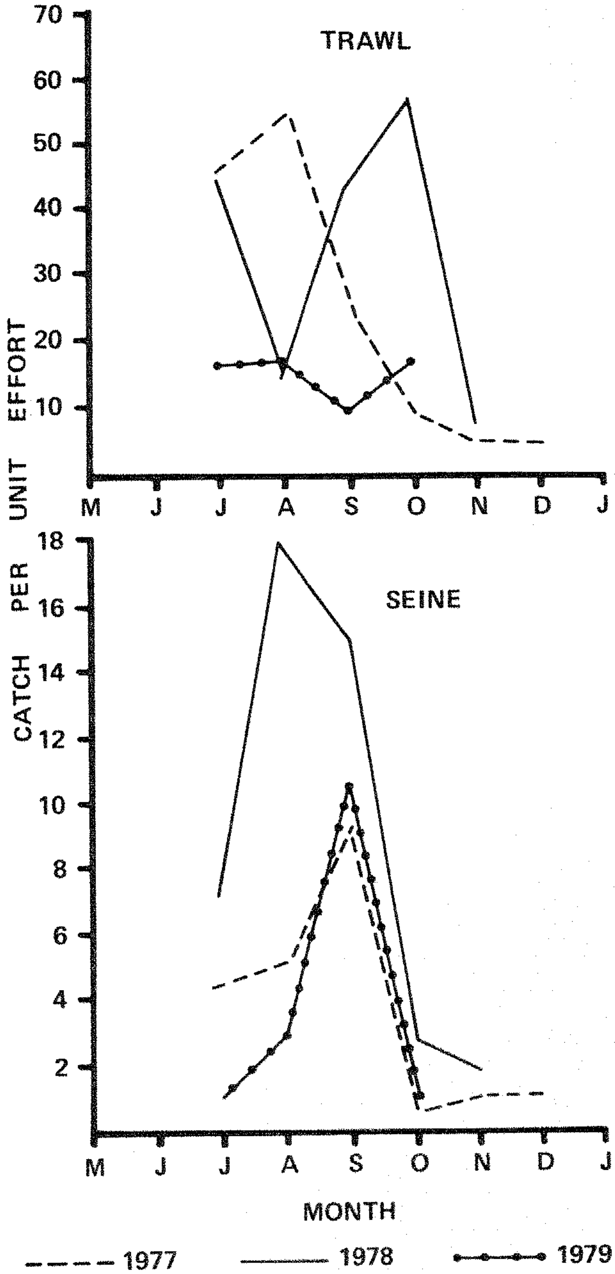


Figure 37. Catch per unit effort of alewife trawl and seine catch in Albemarle Sound during 1977-79 (from Johnson et al. 1979).

seasonal migrations (Copeland et al. 1974b). These adaptations permit the rapid proliferation and growth of animal populations during the optimal season of food production and energy availability. Young-of-the-year postlarvae and juveniles experience their most rapid growth rates in the sound at the time of maximum food availability. This fast growth of young, rather than reproduction, gives rise to the concept of the estuary as a nursery. Egg production and hatching usually take place in an area of relative stability: far upstream in the case of the striped bass and river herring, and in the stable temperatures and salinities of the near-shore ocean for the blue crab sciaenids and other fish species. These hatchery areas are connected in such a way as to allow the eggs and larval forms to drift into the highly productive coastal system. Thus, migrating stocks become part of the estuarine energy cycle; they are integrated into the ecosystem and then released to emigrate to yet another system. In this way, the estuaries along the coast are interconnected through the migration of energy and biomass. This pattern of resource use among functional groups of fishes (anadromous, catadromous, and migratory) maximizes the ecological efficiency of the sound.

In summary, typical spatial and temporal relationships in Albemarle Sound involve the ocean on one end and the freshwater regime on the other. Anadromous fishes like river herring and striped bass "run" through the sound from the ocean to spawn in the freshwater tributaries, usually during the early spring. Then, in concert with freshwater inflows, developing young take advantage of the high productivity in Albemarle Sound and use it as a nursery. They may then leave the sound during the fall to return to the oceanic adult population pool. The migrating fisheries, such as the spot and Atlantic croaker, will spawn in the ocean during the winter and enter the sound during the spring. The sound serves as a nursery for these species during the late spring and summer until the juveniles migrate back to the ocean.

4.4 CONSEQUENCES OF MAN'S IMPACT

One prominent consequence of human encroachment in the Albemarle Sound Estuary has been the construction of dams on major river systems. Dams limit the distance that anadromous fish can run upstream to spawn (Walburg and Nichols 1967). The catch of American shad in the sound has drastically decreased in the past few decades, primarily because dams limit spawning runs up the Roanoke River.

The spawning success of striped bass is dependent upon adequate river flow at the time of spawning. Construction of Kerr Lake, Gaston Lake, and Roanoke Rapids Lake has altered the flow of the Roanoke to the extent that striped bass spawning is thought to be influenced (Hassler et al. 1981). To hatch, striped bass eggs must be buoyed in the water by adequate flow but not washed out of the spawning area by too much flow. Herring and shad also require high flows, but the flow must be manifested in slowly moving water over the floodplains (Pate 1972).

The construction of reservoir dams on the tributary streams not only influences fishes' spawning runs, but it also may impact the productivity of estuaries such as the sound (Copeland 1966). This impact is brought about by the smoothing out of seasonal variations in flow rates that may be necessary for flushing and maintaining the balance of materials in the receiving estuary.

The quality of surface waters is affected by pollution from point sources and nonpoint sources (Soil Conservation Service 1981). Inputs of materials from these sources are greatly influenced by development and activities on the land (North Carolina Division of Environmental Management 1982). In the Albemarle basin, the amount of phosphorus in the receiving waters is estimated to be about three times the normal background levels, and nitrogen is estimated to be about twice the background levels (North Carolina Division of Environmental Management 1982) (see Section 3.2). The consequences of these excess nutrient loads are changes in the phytoplankton composition in Albemarle Sound and development of bluegreen algal blooms (Stanley and Hobbie 1977; Bowden and Hobbie 1977).

The Chowan River, a major tributary of Albemarle Sound, has experienced severe problems attributed to declining water quality as a result of excessive nutrient inputs during the past decade (North Carolina Division of Environmental Management 1979, 1982a; Sauer and Kuenzler 1981; Paerl 1982). Nuisance blue-green algal blooms have been the most noticeable manifestation of the Chowan's water quality problem (Witherspoon et al. 1979; Paerl 1982). The Chowan situation is mentioned here as a case example of estuarine response to the consequences of man's actions on the watershed.

A nutrient budget has been developed for the Chowan basin (Table 13) and nonpoint sources have been identified as major sources of nutrients that impact the estuarine ecosystem. The loadings of nitrogen and phosphorus, which have been

Table 13. Area yield estimates of annual nutrient inputs to the Chowan River Watershed (North Carolina Division of Environmental Management 1982).

Source	Area (km^2)	Nitrogen loading (kg x 10^5/yr)	Phosphorus loading (kg x 10^4/yr)
Nonpoint			
Precipitation[a]	77	0.67	0.50
Agriculture	2308	14.42	20.89
Forests[b]	9615	15.87	9.61
Urban	114	0.60	0.60
Point			
Union Camp	-	3.22	7.17
C.F. Industries	-	1.99	0.00
Other industrial	-	0.57	1.71
Municipal	-	3.03	7.65
Total	12,114	40.37	47.59

[a]Estimated inputs to Lower Chowan River (Holiday Island to Edenhouse).
[b]Includes wetlands.

linked to the development of nuisance blue-green algal blooms (Sauer and Kuenzler 1981; Paerl 1982), vary as a function of flow (North Carolina Division of Environmental Management 1982). Blue-green algal blooms were largest during the years 1972 and 1978, which had high spring tributary discharges and relatively long water residency time during the summer. A more subtle aspect of Chowan River eutrophication is the trend of increasingly higher summer chlorophyll values during the past decade (North Carolina Division of Environmental Management 1982).

Other indications of declining water quality in the Chowan River include fish kills (Johnson 1982), declining commercial fisheries (Street 1982), and decreases in recreational activities (North Carolina Division of Environmental Management 1982).

There is some evidence that overfishing has decreased some of the anadromous fish stocks in Albemarle Sound (Street et al. 1975). Prior to 1970, the total river herring catch in Albemarle Sound exceeded 7 million kg/yr (15 million lb/yr), but decreased to about 3 million kg/yr (6 million lb/yr) by 1975 (Figure 46). Virtually the entire harvest of river herring inshore is composed of sexually mature fish while most of those taken in offshore samples were immature (Street et al. 1975). This pattern was also the case in the herring catch in Virginia. The offshore trawl fishery, which began in 1967, takes all age groups of the ocean population indiscriminately. Prior to the initiation of the offshore trawl fishery (particularly by foreign fleets), the total inshore harvest was fairly stable with several year classes represented in the fishery. Data collected by the North Carolina Division of Marine Fisheries indicate that the total herring population was reduced by harvesting all age groups. Since the cessation of the offshore trawl fishery, coinciding with the enactment of the fisheries conservation zone, stability in the harvest has returned. Though stable in its yield, the population level is much lower than it was before the tremendous fishing effort of the late 1960's and early 1970's.

The long-term residents around Albemarle Sound claim that there has been a change in the salinity patterns of the sound (Stick 1982). Reportedly, high salinity water historically penetrated Albemarle Sound up to the Chowan River in late summer during dry years. When that occurred, the fishing was said to be better than it is today. While documentation is not available to verify these reports, it is reasonable to assume that saltwater intrusions may have occurred during most years. Prior to impoundment of the reservoirs on the Roanoke River, there was normally a period of low flow during late summer. After the reservoirs were constructed, maintenance of prescribed water levels in the lakes required a smoothing of flow variations (see Section 2.5). During the drought conditions of 1981, saltwater penetrated the sound up into the Chowan River. The usual blue-green algal bloom did not occur and production of other phytoplankton was increased (Dr. Hans Paerl, University of North Carolina Institute of Marine Sciences, Moreherd City; pers. comm.). If this scenario holds for pre-impoundment conditions, then the use of the Roanoke River for special reservoirs has certainly decreased Albemarle Sound productivity and its role in commercial fisheries.

CHAPTER 5

FISHERIES

5.1 COMMERCIAL FISHERIES

Fishing has been an important activity (Figure 38) in Albemarle Sound since colonial times (see Section 1.3). The early settlers depended upon the sound for food and used salt river herring as currency (Street 1982) from the Royal Port of Edenton to a number of the islands of the West Indies. Traditional methods of fishing are still used around the sound (Figures 39 and 40), particularly in the more isolated coastal communities (Maiolo and Orbach 1982), and commercial fishing is still primarily small scale.

The total landings of finfish from Albemarle Sound in recent years (1969-80) range between 10 million kg (23 million lb) to about 4 million kg (9 million lb) (Table 14). The annual value ranged from about $700,000 in 1970 through 1972 and $1.7 million in 1978 (Table 14). These data are an accumulation of statistics from the North Carolina Division of Marine Fisheries County Landings data from 1967 through 1980 (Street 1982).

Figure 38. Traditional herring fishery (photo courtesy of the North Carolina Department of Archives and History).

Figure 39. Commercial fishing (photo by Gene Furr).

Figure 40. Long netting in Albemarle Sound (photo by Gene Furr).

Table 14. Total commercial fisheries landings from Albemarle Sound, 1967-80 (from Street 1982).

Year	Total pounds x 1,000	Total value x $1,000	Percent of State landings
1967	21,627	795	9.6
1968	18,804	769	8.1
1969	23,276	995	10.6
1970	14,598	684	8.4
1971	16,600	679	11.6
1972	14,645	694	8.3
1973	11,314	767	8.2
1974	9,906	864	4.8
1975	9,071	889	3.8
1976	10,019	1,185	4.4
1977	12,411	1,355	4.9
1978	11,674	1,679	3.9
1979	9,700	1,409	2.5
1980	10,012	1,343	2.8

The catch from Albemarle Sound has traditionally been dominated by blueback herring and alewife, commonly referred to collectively as river herring (Table 15). The total landings of river herring during recent years ranged between about $200,000 in 1970 to over $400,000 in 1977 (Table 16). Most river herring are caught in spring by netting in the western third of the sound and the mouths of the major tributaries of that area (Figure 41a).

The striped bass is another anadromous fish taken in commercial quantities in the Albemarle Sound area from fall through spring (Street 1982). It is taken commercially in all areas of the sound (Figure 41b), and the landings range from over 400,000 kg (1 million lb) in 1968 to less than 136,000 kg (300,000 lb) in 1980 (Table 15). The average price per pound has increased so that the value of striped bass landings in Albemarle Sound in 1980 was around $300,000 per year (Table 16).

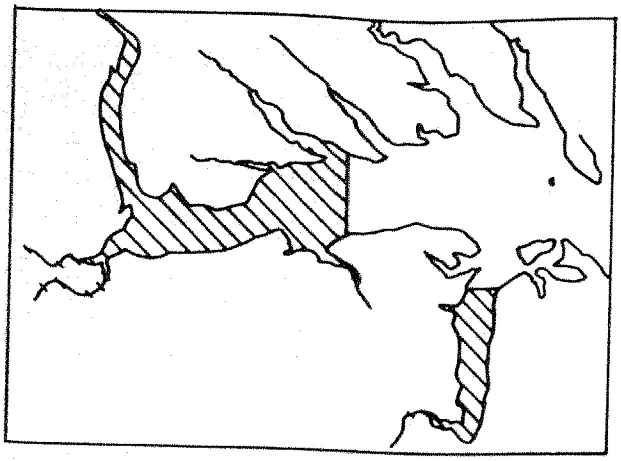
Three indigenous species make up a significant portion of the commercial landings in Albemarle Sound. Two major species of catfish (channel and white catfish) are taken in the western portion of the sound (Figure 42a) using pots and trotlines (Street 1982). Catfish are taken year-round and range in landings from over 1.1 million kg (2.5 million lb) in 1971 to 0.6 million kg (1.3 million lb) in 1980 (Table 15). The annual value of

Table 15. Commercial landings of finfish (1,000 lb) from Albemarle Sound, 1967-80 (from Street 1982).

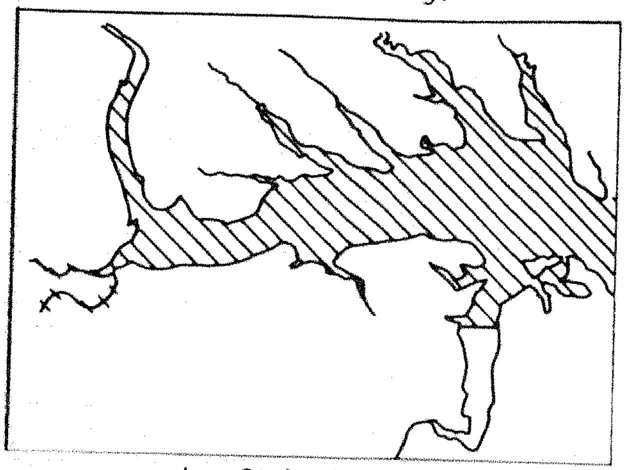
Year	River herring	Catfish	Striped bass	White perch	Others
1967	18,355	1,670	808	343	377
1968	15,077	1,655	1,066	253	602
1969	19,523	1,788	753	184	426
1970	11,291	1,636	675	193	675
1971	12,712	2,518	409	333	82
1972	11,233	2,319	251	163	305
1973	7,867	1,914	417	129	380
1974	6,127	1,706	417	212	889
1975	5,861	1,586	596	221	575
1976	6,371	1,449	601	161	890
1977	8,513	2,036	435	198	592
1978	6,564	1,477	498	470	801
1979	4,984	1,438	301	258	1,103
1980	5,110	1,301	296	48	2,330

Table 16. Value (1,000 dollars) of commercial finfish landings from Albemarle Sound, 1967-80 (from Street 1982).

Year	River Herring	Catfish	Striped bass	White perch	Other
1967	316	261	136	41	38
1968	228	238	222	25	44
1969	297	258	153	21	217
1970	184	280	145	27	39
1971	203	276	90	41	32
1972	196	323	68	21	33
1973	212	280	139	20	42
1974	243	200	139	39	113
1975	212	264	155	40	92
1976	335	287	278	26	140
1977	421	417	217	28	92
1978	285	332	403	119	255
1979	306	287	281	67	202
1980	366	286	296	11	225

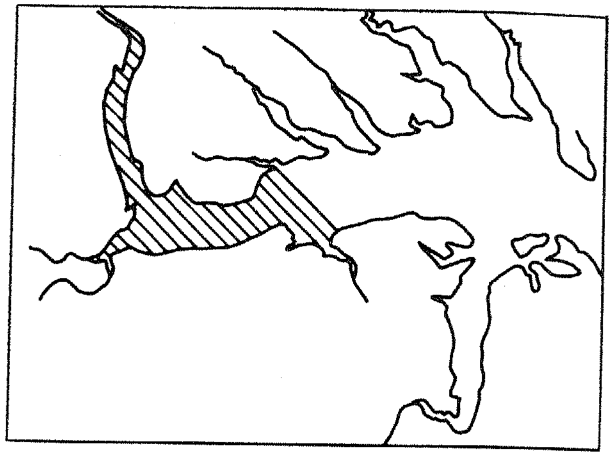


a. River herring.

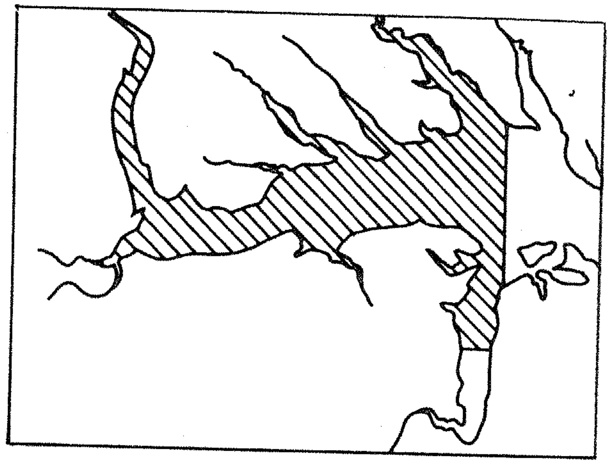


b. Striped bass.

Figure 41. Fishing areas for commercial catch of anadromous fish in Albemarle Sound (from Street 1982).



a. Catfish.



b. White perch.

Figure 42. Fishing areas for commercial catch of indigenous fish in Albemarle Sound (from Street 1982).

the catfish catch in Albemarle Sound is about $300,000 per year (Table 16).

The third indigenous species in the Albemarle Sound commercial catch is white perch. White perch are taken by gill nets throughout most of the sound during the fall and winter, and by pound nets in the Chowan River along with river herring during the spring (Figure 42b). Landings generally range between 45,000 and 200,000 kg/yr (100,000 and 500,000 lb/yr); the lowest catch on record was less than 22,000 kg (50,000 lb) in 1980 (Table 15). The annual value of the white perch landings is generally less than $50,000 per year, with the exception of 1978 (when the catch was the highest on record) when their value exceeded $100,000 (Table 16). This fish has been severely affected by the red sore disease (see Section 3.3), especially during the late 1970's and early 1980's (Johnson 1982).

Other species of finfish commercially taken in Albemarle Sound are American eels, spot, and Atlantic croaker. Commercial landings have recently increased so that by 1980 they exceeded 900,000 kg/yr (2 million lb/yr) in weight (Table 15) and $200,000 in value (Table 16). As the commercial landings of river herring, striped bass, and white perch decrease, the landings of other species are expected to increase as fishermen exert extra effort to fill their catch (see Section 5.3).

Blue crab constitute a major shellfishery in Albemarle Sound, particularly in recent years (Street 1982). Blue crabs are primarily taken during warm weather in the central to eastern portion of the sound (Figure 43). The landings of blue crabs were almost 800,000 kg/yr (2 million lb/yr) in the late 1970's, an increase from about 45,000 kg (100,000 lb/yr) in the late 1960's (Table 17). The value of blue crab landings is nearly $300,000 per year (Table 16), making the value of blue crabs comparable to that of striped bass, catfish, and river herring in Albemarle Sound.

The blue crab fishery (Figure 44) has become commercially important in recent years and is expected to continue to increase in importance in Albemarle Sound. One reason for this is that it is principally a warm-weather fishery, whereas most other fisheries (except catfish) are cool-weather fisheries. This is attractive to many commercial fishermen because it provides them a fishery during the so-called off-season.

The total annual commercial fisheries catch in North Carolina exceeded $50 million in 1979, 1980, and 1981 (Street 1981). As indicated in Table 14, the percentage of the North Carolina catch from Albemarle Sound has declined to less than 3% of the total. Since Albemarle Sound constitutes about 20% of the total estuarine area in North Carolina, its commercial fishery catch is comparatively small. Historically, the percentage of total landings from Albemarle Sound amounted to a figure closer to its ratio in area (Street 1982); thus, the fishermen's feeling that the fishery is "depressed" is real (North Carolina Division of Environmental Management 1982).

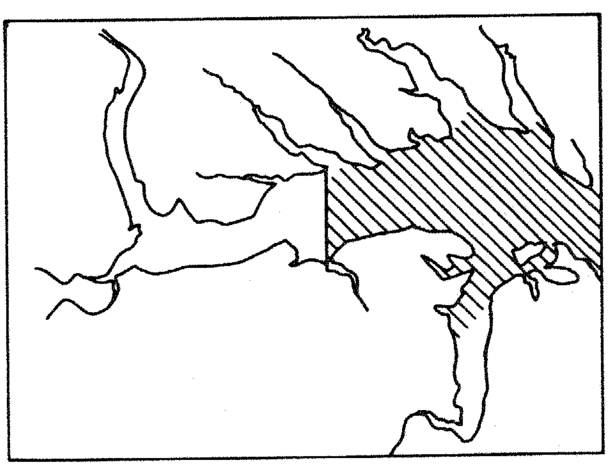


Figure 43. Fishing area for commercial catch of blue crabs in Albemarle Sound (from Street 1982).

Table 17. Commercial landings (1,000 lb and dollars) of blue crabs from Albemarle Sound, 1967-80 (from Street 1982).

Year	Landings	Value
1967	64	3
1968	152	12
1969	602	50
1970	128	8
1971	546	38
1972	394	53
1973	607	74
1974	555	55
1975	231	26
1976	548	119
1977	637	127
1978	1,717	286
1979	1,632	266
1980	969	158

5.2 RECREATIONAL FISHERIES

Recreational fishing (Figure 45) has been a traditional activity in Albemarle Sound for over 300 years. Striped bass (or rockfish, as locally known) has been one of the more popular recreational fisheries of the sound (Hassler et al. 1981). White perch numerically constitute the largest portion of the recreational catch in Albemarle Sound. Other species sought by sport fishermen include yellow perch, spot, and Atlantic croaker.

Creel censuses were conducted on the striped bass recreational fishery in Albemarle Sound by W.W. Hassler of North

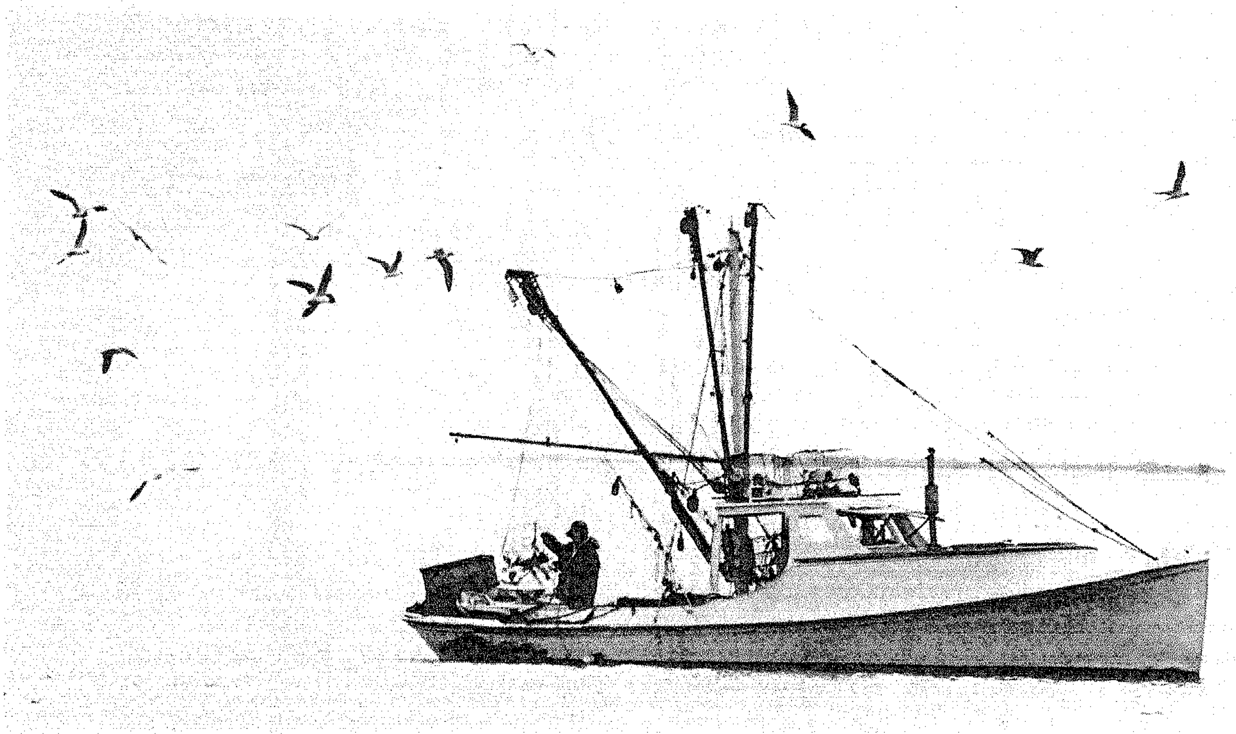


Figure 44. Crab trawler (photo by Steve Murray).

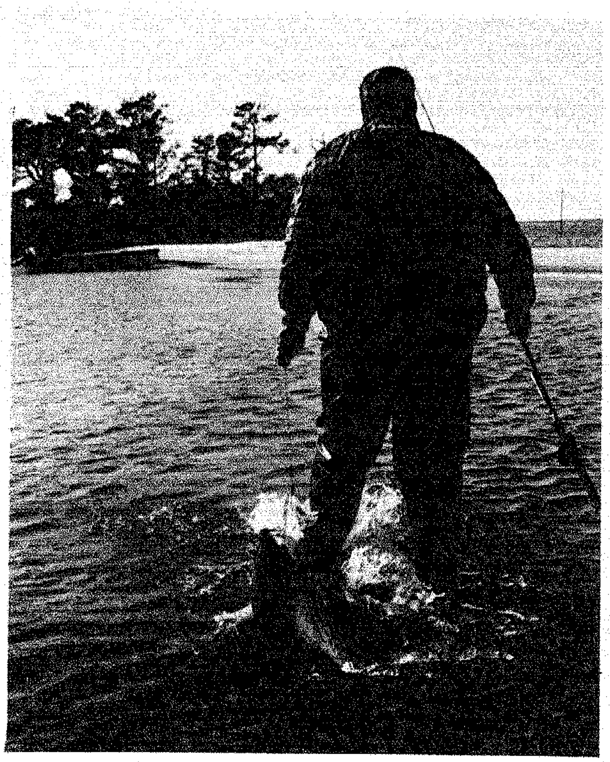


Figure 45. Striped bass fisherman (photo by Joel Arrington).

Carolina State University from 1967 through 1973, and by the North Carolina Wildlife Resources Commission from 1977 through 1979. In general, the fishing effort and major catches were concentrated throughout the cooler months of the year; the best striped bass fishing was from October through April (Hassler et al. 1981). The most intensive fishing in Albemarle Sound was in the vicinity of Mann's Harbor, East Lake, Pasquotank River, Yeopim River, Gum Neck, Alligator River, Shipyard Landing, and Perquimans River. The recreational catch of striped bass in Albemarle Sound has declined from 96,000 fish in 1970 to (in a combined effort of 11,000 boat days) a low of 6,000 in 1979 (Table 18). The catch per unit effort (CPUE) has also steadily declined in recent years (Table 18).

More white perch are taken by sport fishermen than any other species in Albemarle Sound. The recreational catch of white perch exceeded 200,000 fish per year during the 1970's (Street 1982). White perch have been severely affected by red sore disease during the mid to late 1970's (see Section 3.3). A large portion of the

Table 18. Catch of striped bass by recreational fishermen in Albemarle Sound (from Hassler et al. 1981; North Carolina Wildlife Resources Commission data).

Year	Catch	Boat days	CPUE[a]
1967	67,000	6,000	11
1968	50,000	8,000	6
1969	62,000	8,000	8
1970	96,000	11,000	9
1971	41,000	12,000	3.5
1972	36,000	8,000	4.5
1973	31,000	6,000	5
1977	33,000	--	--
1978	14,000	--	--
1979	6,000	--	--

[a]CPUE = Catch per unit effort.

recreational catch in the late 1970's was affected and the desire of recreational fishermen to catch perch was greatly reduced, although the affected fish are edible.

5.3 FISHERIES TRENDS

The total fishery yield in Albemarle Sound has declined during the past decade (Figure 46). The catch has decreased from a high of over 10 million kg (23 million lb) in 1970 to about 4.5 million kg (10 million lb) in 1980. Much of this decline has been in the river herring fishery, made up of the blueback herring and the alewife (Street 1982). This decline has primarily been attributed to a decline in the water quality of Albemarle Sound and its tributaries (Johnson 1982).

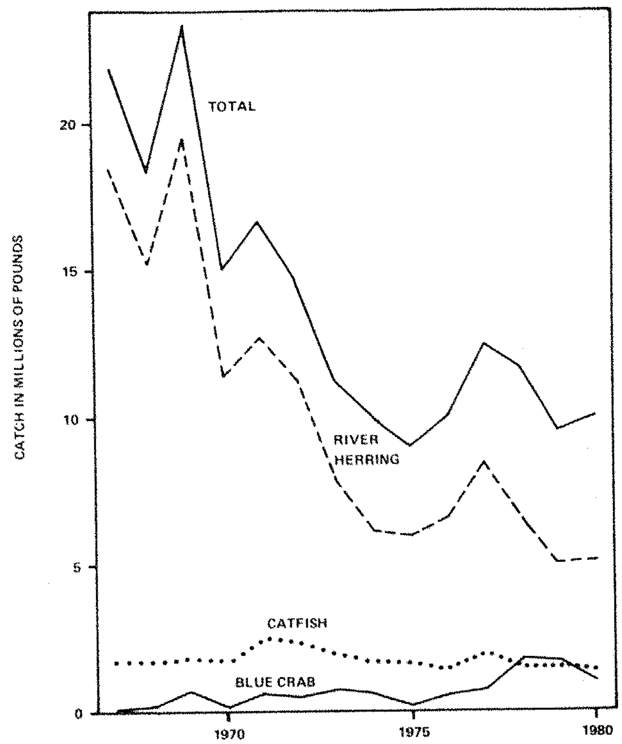


Figure 46. Trends in commercial landings from Albemarle Sound, 1967-1980 (from Street 1982).

The catfish fishery in Albemarle Sound seems to be relatively consistent in its production, and the blue crab catch has increased in recent years. Perhaps the catfish is more tolerant of declining water quality in the tributaries than anadromous species, and therefore, is capable of maintaining a stable population (Klimek 1982; North Carolina Division of Environmental Management 1982; Paerl 1982). The blue crab catch has increased primarily because of a large increase in fishing effort as fishermen turn to summertime fishing to supplement declining, traditional wintertime fishing income (Street 1982).

CHAPTER 6

MANAGEMENT IMPLICATIONS

6.1 ECONOMIC PARAMETERS

Three general levels of management are applicable to Albemarle Sound: single-species, multi-species, and entire-estuary management. Economic parameters important in management decisions will largely depend on the level of management being considered. Single-species management involves one group of parameters; multi-species management, a larger group of parameters. Management of an entire estuary involves a still larger group of parameters because water use by sectors of the economy other than fisheries becomes a direct concern.

The term "management" generally refers to taking some action or actions designed to achieve a given goal. Even at the simplest level of single-species management, a large number of options are often available to managers or planners of the sound. Suppose for example, a fishery catch has fallen because of too much fishing pressure. (In the case of Albemarle Sound, increased fishing pressure is not unusual for fisheries in which costs of entering are relatively low.) To reduce the amount of fishing pressure, the fishery management agency may decide to set size limits on the fish to be landed, shorten fishing seasons, or set aside protected areas. Fishing pressure could be further reduced by taxing the catch or vessels, reducing the number of licenses issued, or assigning quotas to fishermen, with total assigned quota equal to the smaller desired catch. Clark (1979) has shown the management tool of assigned quotas to be as economically efficient as a tax on catch, which is generally regarded as highly effective, but politically impractical. Assigned quotas may not be so politically impractical, and if they are marketable (i.e., if fishermen could buy and sell their quota), could result in benefits accruing to fishermen instead of government, as happens in the case of taxes on catch. A smaller catch may be necessary for some period of time to allow stocks to rebuild. Once stocks are larger, larger catches may be possible without permanently diminishing the stock.

Revenue generated from a fishery depends upon the biological parameters affecting population and growth, and upon economic parameters such as price and cost of harvesting. Fish stocks are similar to capital assets in that they yield a flow of revenue over time. That flow of revenue from landings each year is critically dependent upon the size of the population and upon the price received from the catch. The population size and the growth of individual fish in that population (as pointed out in earlier sections) depend upon water quality and characteristics such as salinity, available food, and water temperature. The demand for any given species affects the price received for the catch and the annual revenue from the fishery. Cost of harvesting depends not only upon prices of those items typically associated with fishing (vessels, fuel, etc.), but it also depends upon the opportunity cost of fishermen. By opportunity cost, we are referring to the income given up by a fisherman in the most profitable use of his time other than fishing. Hence, other employment opportunities will affect the amount of time an individual allocates to fishing and, also, the total number of individuals in a fishery at any point in time. As an example, many farmers in the Albemarle area are part-time fishermen, but they are far less likely to be in the fishery during planting and crop harvesting seasons than at other times. During peak farm seasons, their opportunity cost of fishing is likely to exceed their expected revenue from fishing. In Albemarle Sound, multiple species management is necessary to provide fishing opportunities between farming activities (i.e., the traditional winter fishery).

If management goals are expanded to improve the net revenue from several or all fish stocks in Albemarle Sound, the management agency then becomes concerned with all fish stocks and harvests simultaneously. Multi-species management involves additional parameters. Factors such as discard (catch of unwanted species or juvenile species) become important. Harvesting one or more target species may adversely affect another species. This practice not only has biological implications, but it has economic implications as well. The species adversely affected may be one that is harvested by another group of fishermen, or it may be one that would be harvested later after the juveniles matured. Hence, future harvests and revenue can be reduced because of the discard (Waters et al. 1980). Two competing groups likely to be important in managing Albemarle Sound's fisheries are commercial and recreational fishermen. Both groups may exploit a single species, such as striped bass, or exploit different species that may be related through the food chain, such as shad and largemouth bass.

Having discussed some issues and options available to fishery managers, we shift our attention to management goals that are water quality-oriented. Water quality is important in considering goals as broad as management of an entire estuary, or as specific as improved fishery yields. As soon as we include improved water quality as a goal, management problems increase. What characteristics of water quality do we identify as our goal and as yardsticks for measuring movement toward that goal? Management is further complicated by unknown relationships between selected water quality parameters and production of fish.

In Albemarle Sound all water quality issues are ultimately related to freshwater runoff. Concern has often been expressed about increased freshwater runoff and its effects on fish production and other uses of the water. The effects include not only those caused by salinity decreases but also the effects of fertilizers, pesticides, and animal wastes inputs that are connected with increasing agricultural use of the land surrounding Albemarle Sound. If our management goal is increased fish production by improved water quality, several questions with important economic implications are raised. What is the relationship between freshwater runoff (ignoring nutrient and pollution loads) and fish production? What are the effects of small changes in salinities, or of localized increased freshwater runoff, on the sound's productivity for specific species? What are the effects of changes in runoff on saltwater versus freshwater species associations? While additional freshwater may reduce Albemarle Sound's productivity for saltwater species, freshwater runoff may have no impact, or even a positive effect, on productivity of freshwater species. To properly evaluate proposed regulations to curtail runoff (that might have negative effects on farm income), a knowledge of such effects of runoff on productivity would be required.

These types of issues will probably arise if management goals include water quality characteristics. As with many management schemes, some people will perhaps gain income, some perhaps lose income. Will the net change be positive? If that cannot be clearly shown, one can seriously question the management goal and practice. And, even if gains outweigh losses, the redistribution of income is not a popular task, particularly as far as those losing income (or potential income) are concerned.

Agriculture has played a major role in the Albemarle area for 3 centuries (Stick 1982); in recent years, however, the tourism and recreation industry (Figure 47) has gained in importance. The

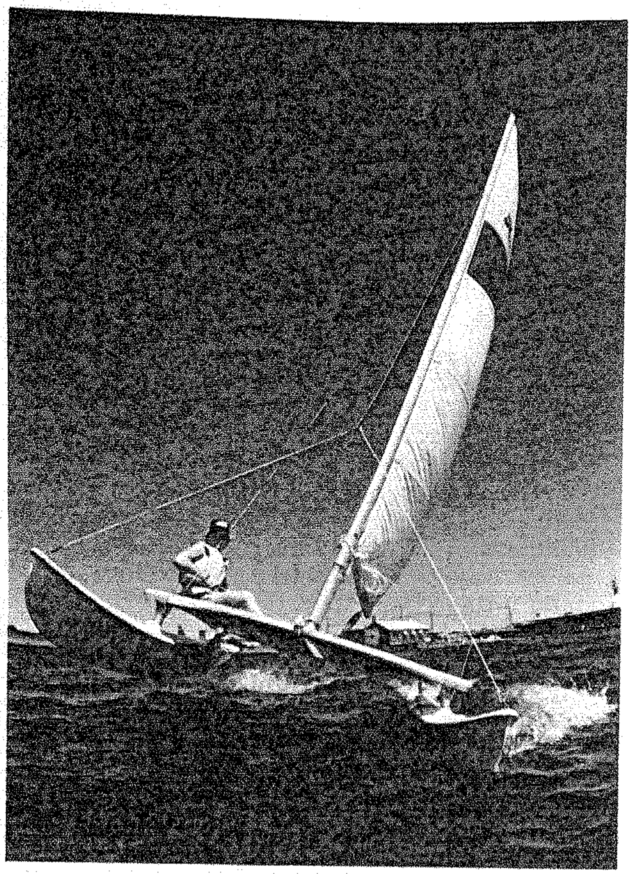


Figure 47. Recreational activity on Albemarle Sound (photo by J. Foster Scott).

relative magnitudes of some of the activities for the 10 counties surrounding Albemarle Sound are the following: 1978 value of farm products sold, $180.2 million (Harwood 1982); estimated travel and tourism expenditures for 1979, $96 million, and for 1980, $104 million (North Carolina Department of Commerce, Raleigh; pers. comm.); dockside value of commercial fishery landings for 1979, $1.4 million, and for 1980, $1.3 million (Table 14). Concerning the recreational expenditures, if the Dare County expenditures are ocean-related and if these are substracted from the total, the area's recreational expenditures for 1979 and 1980 are then $25.5 million and $29.2 million, respectively. One might also speculate that a significant part of the sound-related recreational expenditures is related to recreational fishing; hence, it is likely that recreational fishing is more important to the area's economy than commercial fishing. These are crude data, however, and speculation is about all they support. The values are comparable only in that they represent receipts to firms in the respective industries. The operating expenses of each industry are quite different and must be subtracted from these totals in order for the figures to be strictly comparable. Other economic multipliers are factored in which make the ultimate impacts of each industry on the overall economy vary even more.

Given these economic activities, their relative magnitudes, and the other characteristics of the Albemarle Sound Estuary, what are some management considerations? First, we need to emphasize one point: management generally is designed to "improve" the allocation of resources, either between activities or between time periods. To improve resource allocation requires specific objectives and understanding of the problem(s) to be solved or, in some fashion, improved. Management has costs: once a clear goal is established, we should look at alternative methods, and the associated costs, of achieving that goal. "Costs" here refers to both income given up by any group as well as those costs incurred by government bodies in managing. Additionally, since the technical production coefficients (the ratio of true costs to benefits) are unknown, any management goal--and the current practices operated upon to achieve that goal--is surrounded with uncertainty. This uncertainty is particularly true of relationships between economic sectors, and we should not rely simply upon value judgments as to what impacts may be. These management implications along with the earlier comments about levels of activities, caution against management that pits one economic activity against another. Most practical tradeoffs are not "all or none," but rather are partial tradeoffs of costs, benefits, and activities. Finally, a second caution might be mentioned regarding management of an estuary. Any given group of resource users perceiving costs or benefits to a proposed action will support or denounce that option, ignoring costs and benefits to other groups of resource users. To condemn such actions is not intended, for they are logical responses. The intent is simply to suggest that management agencies look at all sides of an issue. The resulting outcome may be settled politically; such outcomes often reflect the underlying economic concerns and conflicts.

The complex nature of the Albemarle Sound fishery complicates the management process. For example, a management goal that includes changes in water characteristics aimed at improved production of both recreational and commercial fisheries may have built-in conflicts. Because of the mix of species in both fisheries, improved production of one group of biologically similar species may reduce production of another group. Improvements in catch-per-unit effort in one recreational fishery may come partially at the expense of another recreational fishery, or the commercial fishery. Albemarle Sound supports both saltwater and freshwater species, and selected species of both are exploited recreationally and commercially. Thus, management is complicated on both counts. Furthermore, goals and subsequent management practices that attempt to improve water quality may also tend to shift the mix of species (saltwater vs. freshwater). Hence, to determine whether the net result of any given management practice is economically beneficial will require detailed analyses and much data. Costs and benefits to other sectors of the local economy of such a goal must also be examined.

Albemarle Sound may well be difficult to manage, or at least to improve in a cost-effective manner. Before management regimes are installed, potential outcomes should be examined. Cost-benefit analysis is one technique for doing so (Danielson 1982). Any change in resource usage through public policy affects costs and revenues over time. The changes in flows of revenues should be evaluated beforehand. In doing so, the important measure is the change in those flows, not the level of flows. Dynamic economic modeling (models that explicitly incorporate time) provides an additional evaluation technique.

6.2 SOCIOLOGICAL IMPLICATIONS

Many economic forces are focused on Albemarle Sound and many potential uses of the sound are in conflict with one another. None of the forces and uses, however, is mutually exclusive of any other. Managing the sound so as to minimize conflicts among different users becomes a major sociological consideration.

Agricultural production is a dominating economic force in the Albemarle Sound watershed and declines in the sound's water quality have been attributed to farming operations. Many farmers around the sound are also engaged in fishing in the sound. Thus, management schemes favoring fishing may meet with less resistance from the agricultural sector than if farmers and fishermen were mutually exclusive groups.

Recreation and tourism, also large economic forces in the area, depend on certain levels of water quality and habitat stability in Albemarle Sound. In general, these are the same water quality variables that are necessary for the maintenance of a commercial fishery (Johnson 1982). Even though management of the environmental quality should be equally acceptable among commercial and recreational fishery interests, there are major differences in social goals of the two groups (Maiolo and Orbach 1982). An outstanding case is the continuing argument over the use of striped bass stocks for commercial versus recreational fishing (Abbas 1982). Recreational fishermen blame the commercial fishery for decreasing the striped bass stocks and making fish more difficult to obtain recreationally. Management schemes designed to address the Albemarle Sound striped bass fishery must take into consideration this and other social conflicts. Furthermore, since the striped bass stocks in Albemarle Sound are probably distinct from the stocks in Chesapeake Bay and other estuaries, a management plan should be of a local economic and social character.

6.3 INSTITUTIONAL AND MANAGEMENT CONSTRAINTS

Management in any estuary is difficult because of multiple jurisdictions and separation of power by the various institutions having management responsibilities. Management is especially difficult in Albemarle Sound since it involves a watershed in two States and must deal with a wide range of environments and their resources. Additionally, a number of Federal, State, and local agencies have management responsibilities dealing with Albemarle Sound and its resources.

Seventy percent of the watershed of Albemarle Sound lies in Virginia and many believe that many of the water quality problems in the Chowan River and western part of Albemarle Sound are the result of activities carried out in Virginia (North Carolina Division of Environmental Management 1982). Indeed, about 70% of the nitrogen loading and 80% of the phosphorus loading in the Chowan River are from the Virginia portion of the watershed (North Carolina Division of Environmental Management 1982). In addition to water quality problems, the city of Norfolk, Virginia, is currently increasing its municipal use of water from the Albemarle watershed, thereby reducing freshwater inflows to Albemarle Sound even further. Because of conflicts in the goals of State governments in Virginia and North Carolina, it has been difficult to resolve water quality improvement problems. Thus, a serious constraint on a management plan for Albemarle Sound is the jurisdictional interactions between two State governments.

Several State and Federal agencies are charged with the responsibility of managing the various resources in Albemarle Sound (Table 19). For example, the North Carolina Division of Marine Fisheries manages the marine fisheries of the State while the North Carolina Division of Wildlife Resources manages the freshwater fisheries of the State. These and other jurisdictions sometimes overlap. Still other agencies are charged with responsibilities for water quality, water management, shellfish sanitation, or peat mining. Many Federal agencies operate by enforcing blanket regulations and have management goals that are sometimes in conflict with the goals of State or local agencies. All these responsibilities and goals need to be coordinated to optimize management activities.

Another constraint faced by would-be managers of Albemarle Sound is the lack of information on some aspects of estuarine structure and function. The considerable information concerning the characteristics of other oligohaline estuarines similar to Albemarle Sound in this country and abroad (see Section 1.5) may be important as background information for making decisions about the sound. From our collective knowledge of all these similar systems, it may be possible to develop innovative management schemes to optimize the resource uses of them all.

6.4 THE CHOWAN/ALBEMARLE ACTION PLAN--A CASE STUDY

The North Carolina Department of Natural Resources and Community Development has developed a plan for managing water quality in the Chowan River (North Carolina Divison of Environmental Management 1982). Research activities have been initiated to determine the causes, characteristics, and best means to control algal blooms in the Chowan River and to prevent them from spreading into Albemarle Sound. Elements of the plan are included here to illustrate how an effective management plan must deal with conflicting uses and multiple interests.

The plan devised a complex and long-term strategy to reduce nitrogen and phosphorus loading in the Chowan River watershed. While both nitrogen and phosphorus are responsible for blue-green algal blooms in the river, the State's management plan primarily addresses phosphorus (Klimek 1982), because phosphorus is thought to be more cheaply and more easily reduced. Furthermore, blue-green algae can fix nitrogen from the atmosphere (Paerl 1982) once they are established, and can proliferate even at low nitrogen concentrations when phosphorus concentrations are high. A model was developed to predict algal response (in terms of chlorophyll _a_ concentrations) to phosphorus loading (Figure 48). This model gives a gradient of verified levels of algae development ranging from very low levels (hypothesized when the watershed was forested) to algal bloom situations with today's loading. The model predicts that a reduction of about 30% to 40% of present

Table 19. Important issues in Albemarle Sound and agencies of responsibility (North Carolina Office of Coastal Management, Raleigh; pers. comm.)

Issue	Agency responsible
Peat mining	N.C. Division of Land Resources N.C. Mining Commission N.C. Office of Water Resources N.C. Office of Coastal Management U.S. Army Corps of Engineers U.S. Department of Energy
Megafarms	U.S. Army Corps of Engineers N.C. Division of Forest Resources
Pollutants	U.S. Environmental Protection Agency N.C. Division of Environmental Management N.C. Office of Water Resources N.C. Office of Coastal Management
Non-point sources	N.C. Division of Environmental Management N.C. Office of Coastal Management
Sewage disposal	N.C. Department of Human Resources U.S. Environmental Protection Agency
Eutrophication	N.C. Division of Environmental Management
Freshwater diversion to Virginia	N.C. Division of Environment Management
Impoundments	U.S. Army Corps of Engineers N.C. Division of Wildlife Resources
Declining fisheries	N.C. Division of Marine Fisheries N.C. Division of Wildlife Resources N.C. Office of Coastal Management N.C. Division of Environmental Management
Industrialization	N.C. Department of Commerce N.C. Division of Environmental Management N.C. Office of Coastal Management

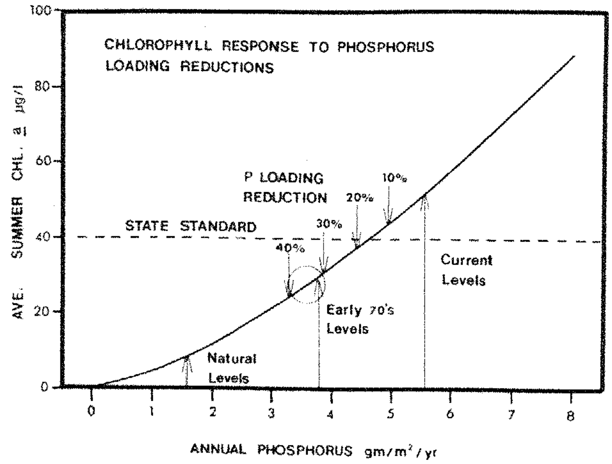


Figure 48. Changes in average summer chlorophyll a in the lower Chowan River in response to changing phosphorus loading (from Klimek 1982).

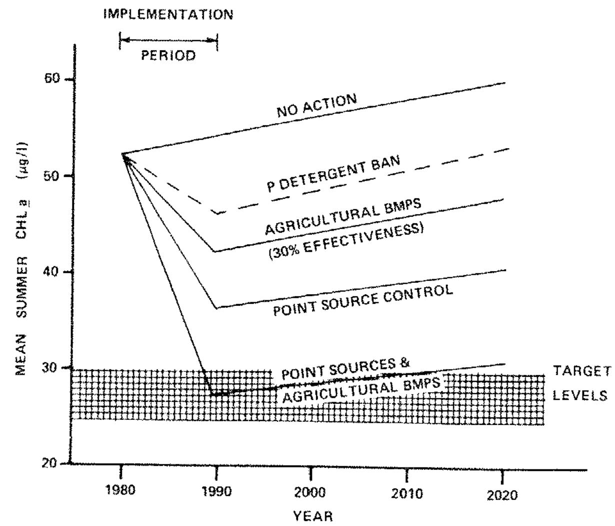


Figure 49. Variation in nutrient management alternative effectiveness due to projected population/land use changes (from Klimek 1982).

phosphorus loading will be required to achieve algae population levels within the management plan target (Figure 48).

With changing land use and population levels, nutrient loadings are projected to increase with time (Figure 49, Klimek 1982). Assuming a 10-year implementation plan, a combination of best management practices (BMP's) in agriculture (i.e., erosion, fertilizer, pesticide and animal waste control), phosphate detergent bans, and reduction of point source nutrient-rich wastewater outputs by treatment and/or alternate disposal were recommended to reduce nutrients to target levels (Figure 49). In addition to proposed 30% to 40% phosphorus input reductions, recommendations were made to reduce nitrogen inputs by 15% to 20%. The legal basis for regulating discharges from point sources would be provided by state designation of the Chowan River as "Nutrient Sensitive Waters."

Thus, the successful implementation of this plan will require the cooperation of industries, municipalities, farmers, the agriculture industry, and monitoring and permitting agencies, as well as a strong public education program. Whether this strategy works and whether the management plan will lead to improved fisheries will not be known for several years.

CHAPTER 7

SUMMARY AND CONCLUSIONS

1. The Albemarle Sound estuarine system is about 243,000 ha (940 mi^2) in area and lies in nine counties of northeastern North Carolina. The sound and its associated tributary estuaries represent a vast complex of fresh to brackish water creeks, rivers, and open water. It is the northermost component of the North Carolina coastal system.

2. Albemarle Sound estuarine system lies within the outer portion of the Atlantic Coastal Plain province, an emergent portion of the ocean's Continental Shelf. The low, flat plain is underlain by fossiliferous sandy clays deposited during past marine incursions. This geologic setting has resulted in a very low, poorly drained land area characterized by extensive swamps and pocosins with organic peat soils that generally thicken eastward.

3. Five different shoreline types characterize the Albemarle Sound estuarine system. Over 43% of the shoreline is classified as low banks; 30%, swamp forest; 18%, high banks; 8%, marshes; and about 1%, bluffs.

4. The area surrounding Albemarle Sound is sparsely populated. Population in the area is expected to increase about 20% over the next 50 years. About 60% of the land in the watershed is forested, but the area devoted to agriculture is increasing. The changing land use results in increased land drainage through a network of canals.

5. The water table from the surface aquifer lies close to the ground surface in much of the area around Albemarle Sound. Recharge comes primarily from rainfall, and the dominant movement of water is lateral.

6. Average annual rainfall is about 125 cm (50 inches), and the highest precipitation occurs during the summer. The highest runoff occurs during the winter. The climate is moderate with an average winter low of about 7°C (44°F) and a summertime average high of 32°C (90°F). Winds are predominantly S to SW and average about 15 to 16 km/hr (9 to 10 mph).

7. The two major sources of freshwater into Albemarle Sound are the Chowan and Roanoke Rivers. The mean total discharge into Albemarle Sound is about 17,000 cfs. A high discharge to sound volume ratio maintains nearly freshwater conditions most of the time. Circulation is mostly influenced by winds.

8. Wetlands around Albemarle Sound are classified as swamp forests, pocosins, and irregularly flooded marshes. Most of the wetlands are pocosins.

9. The aquatic environment is typically oligohaline; the average salinity does not exceed about 5 ppt. Mean monthly water temperatures range between 5°C (41°F) in the winter and 28°C (82°F) in the summer.

10. Phytoplankton distribution is patchy and concentrations are highly variable. Chlorophyll *a* concentrations reflect nearly eutropic conditions, especially during summer. Blue-green algae reach bloom conditions during the summer of most years, especially in the lower reaches of the Chowan River.

11. Concentrations of organic matter in the incoming water are high and are an important subsidy to Albemarle Sound's productivity. The highest concentrations occur during late summer and fall, corresponding to plant die-off at the end of the growing season.

12. Nutrient concentrations are patchy but adequate for abundant phytoplankton growth. Phosphorus and nitrogen concentrations are highest during winter and lowest during summer. The most abundant form of inorganic nitrogen is nitrate, but there are significant concentrations of ammonia and nitrite. The organic nitrogen pool is large and may be the most abundant form of nitrogen in the estuary.

13. A major microbiological problem, commonly referred to as red sore disease, affects the fisheries of Albemarle Sound. Also, a large portion of Albemarle Sound is closed for commercial shellfishing because of high concentrations of coliform bacteria.

14. No studies have been conducted in Albemarle Sound to assess the phytoplankton, zooplankton, or benthic communities, although current investigations of these groups in the Chowan River may fill these gaps in our knowledge of the estuary. Dense beds of the freshwater clam *Rangia cuneata* occur in the estuary.

15. Nekton diversity in Albemarle Sound is low, characteristic of oligohaline estuaries. The largest biomass occurs during winter and summer and the highest numbers occur during spring.

16. Four major population types characterize the fisheries of Albemarle Sound. Anadromous fish, primarily blueback herring, alewife, striped bass, and shad, make spawning runs up the tributaries during spring, and the young enter the estuary during summer. Indigenous fish (e.g., catfish, white perch, yellow perch) make up a large part of the winter biomass. A migratory population (e.g., blue crabs, spot, Atlantic croaker) inhabits the eastern part of the sound on a seasonal basis. One important catadromous species (American eel) inhabits the estuary and leaves the area for oceanic spawning.

17. Fishing has been important in Albemarle Sound since colonial times. Landings of finfish from Albemarle Sound have decreased during the past decade. This catch has traditionally been dominated by river herring. There is some evidence that overfishing has decreased several of the anadromous fish stocks in the sound.

18. Landings of catfish and blue crabs have increased in recent years. As some of the traditional catch decreases, the catch of other species is expected to increase as fishermen try to supplement their income.

19. Recreational fishing has traditionally focused on striped bass and white perch. Both species show declines.

20. Food chains and trophic structure in the Albemarle Sound ecosystem have not been studied, but oligohaline estuaries generally have abbreviated food chains. Most of the fishes are plankton or zoobenthos consumers. Because of the large influence of tributary inputs, the basic trophic level of the oligohaline system is typically dominated by organic detritus washed in from the watershed.

21. Fish using estuaries like Albemarle Sound shift their food preference as they mature and grow. The young of these fish consume zooplankton while in the nursery, but at the juvenile

and adult stages they shift to benthos and fish.

22. Estuarine nursery areas in Albemarle Sound are typically the nearshore shallow areas. These areas support large populations of juvenile fishes and shellfish important to the recreational and commercial fisheries of the area. Most of the species using western Albemarle Sound nursery areas are anadromous fish such as striped bass, alewife, and blueback herring. A few migratory species use the more saline eastern portion of Albemarle Sound as a nursery area.

23. The seasons in Albemarle Sound are defined by a combination of tributary inflows and water temperature. Freshwater flow from the tributaries is greatest during late winter and early spring. Materials carried into the system from upland drainage stimulate phytoplankton productivity as the temperature increases. This is followed quickly by an increase in zooplankton production.

24. Spawning migrations of the anadromous fishes using Albemarle Sound occur during early spring and are timed such that the peak abundance of juveniles in the sound corresponds to the time of maximum production within the sound.

25. The typical spatial and temporal relationships in Albemarle Sound involve the ocean on one end and the freshwater regime on the other end. The anadromous species spawn in the freshwater tributaries during the early spring of each year. The young take advantage of the high productivity in the Albemarle Sound nursery and then may leave the sound during the fall to return to the ocean adult pool. The migrating fisheries such as spot and Atlantic croaker spawn in the ocean during the winter and the young enter the sound during the spring. The sound serves as a nursery for those species during the late spring and summer. Juveniles migrate back to the ocean adult pool during fall.

26. A prominent example of human activity in the Albemarle Sound ecosystem has been the construction of dams on major river systems. This activity has drastically decreased the spawning runs of anadromous fish in the rivers and has affected their spawning success because of altered river flow. The construction of reservoir dams has impacted the productivity of the sound by smoothing out seasonal variation in flow rates, which may be necessary for flushing and maintaining the balance of materials in the receiving estuary.

27. The quality of surface waters is affected by pollution from point sources and nonpoint sources. Nutrient and organic inputs from these sources are greatly influenced by development and activities on the land.

28. The balance of freshwater inflow and estuary volume is essential to maintain the traditional habitat character. Albemarle Sound biological systems are adapted to the predominantly brackish conditions, and continued present levels of production are dependent on these conditions. Seasonal highs and lows of freshwater input are essential to maintaining production.

29. Recent reported values of economic activities in the Albemarle Sound region are: $180 million for farm products; $100 million for travel and tourism; and $1.4 million for commercial fishery landings. Obviously, management agencies must look at all sides of a management issue and at the relative economic returns.

30. Management of Albemarle Sound is especially difficult. A large portion (70%) of the watershed lies in Virginia and the sound lies in North Carolina. Thus management involves goals of two States. Federal and State agencies have overlapping jurisdictions over different resources of the sound, sometimes raising conflict in setting goals. Therefore,

institutional goals and activities can be troublesome when attempts are made to develop a comprehensive management plan.

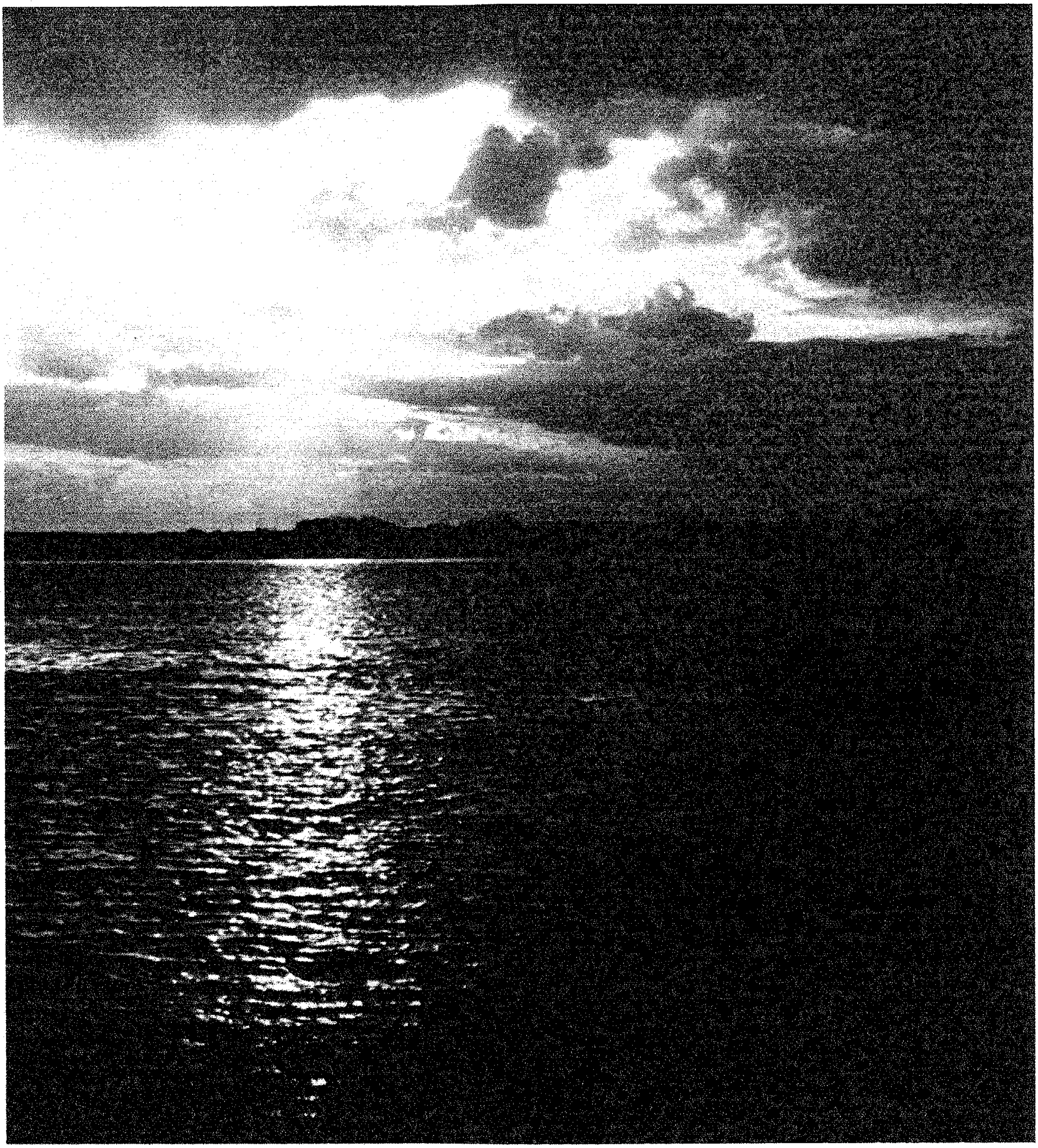


Figure 50. Albemarle Sound (photo by Dixie Berg).

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16. Abstract (Limit: 200 words)

Albemarle Sound, a large oligohaline estuary in northeastern North Carolina, constitutes a significant portion of North Carolina's coastal system. It is shallow, wind dominated, and strongly influenced by freshwater inflow. These conditions, combined with limited oceanic access and exchange, maintain fresh- to brackish water conditions throughout most of the estuary during the year.

The nekton are the most well-known biological component of this extensive estuarine system. Albemarle Sound is an important nursery area for a number of anadromous and migratory fish as well as the blue crab and supports fisheries for many of these species. Other biological components (phytoplankton, zooplankton, and benthos) in the estuary are less well studied.

Declining fisheries, algal blooms in freshwater tributaries, and changing patterns of land and water use are among the critical issues facing managers of Albemarle Sound. This report discusses current steps being taken toward holistic management and provides a state-of-the-art information base and ecological synthesis of the estuary and its watershed.

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Estuaries, brackish water, ecology, hydrology, climate, geology, fisheries, economic factors, nitrogen, phosphorus, nekton, phytoplankton, coliform bacteria, detritus

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